MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

A National Center of Excellence in Advanced Technology Applications

ISSN 1520-295X

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Technical Report MCEER-99-0008

April 12, 1999

This research was conducted at EQE International, Inc. and was supported in whole or in part by the National Science Foundation under Grant No. BCS 90-25010.

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Publication Date: April 12, 1999
Submittal Date: February 16, 1999

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Task Number 95-3201

NSF Master Contract Number BCS 90-25010

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Preface

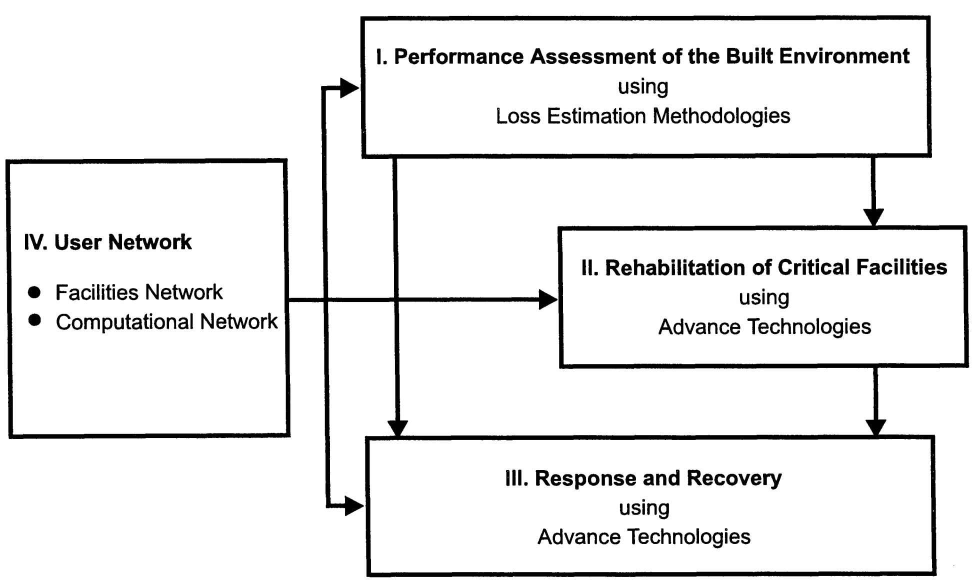
The Multidisciplinary Center for Earthquake Engineering Research (MCEER) is a national center of excellence in advanced technology applications that is dedicated to the reduction of earthquake losses nationwide. Headquartered at the University at Buffalo, State University of New York, the Center was originally established by the National Science Foundation in 1986, as the National Center for Earthquake Engineering Research (NCEER).

Comprising a consortium of researchers from numerous disciplines and institutions throughout the United States, the Center's mission is to reduce earthquake losses through research and the application of advanced technologies that improve engineering, pre-earthquake planning and post-earthquake recovery strategies. Toward this end, the Center coordinates a nationwide program of multidisciplinary team research, education and outreach activities.

MCEER's research is conducted under the sponsorship of two major federal agencies: the National Science Foundation (NSF) and the Federal Highway Administration (FHWA), and the State of New York. Significant support is derived from the Federal Emergency Management Agency (FEMA), other state governments, academic institutions, foreign governments and private industry.

The Center's NSF-sponsored research is focused around four major thrusts, as shown in the figure below:

- quantifying building and lifeline performance in future earthquake through the estimation of expected losses;
- developing cost-effective, performance based, rehabilitation technologies for critical facilities;
- improving response and recovery through strategic planning and crisis management;
- establishing two user networks, one in experimental facilities and computing environments and the other in computational and analytical resources.



This report summarizes a multi-year research effort to develop a detailed methodology to assess and improve the functional reliability of equipment systems in critical facilities following earthquakes. The emphasis was on performing a rapid assessment by regular facility staff, and consists of four major steps: systems definition, evaluation of individual components, systems evaluation, and risk management. The program is intended for use by engineers, building officials, owners and others interested in assessing and improving the capability of a facility to maintain its structural integrity. This report is divided into three parts. Part A is a handbook, written as an instruction for users. Part B contains supporting documentation and the technical rationale for the approach. Part C provides an example set of model code provisions using this approach. It is intended to demonstrate how the approach can be incorporated into a format that can be used by designers or to evaluate existing facilities.

EXECUTIVE SUMMARY

This document summarizes a multi-year research project in the development of a detailed methodology to assess and improve the functional reliability of equipment systems in critical facilities following earthquakes.

The overall program is intended to be used by engineers, building officials, owners, and other individuals interested in assessing and improving the capability of a facility to provide critical services.

Current building design standards are primarily intended to preserve life safety through maintenance of the structural integrity of buildings and critical safety systems, such as fire protection. Some governing bodies recognize that critical facilities, such as hospitals, are required to not only survive an earthquake without structural failure but also to be operational during, and immediately following, a seismic event.

An approach to improve the reliability of equipment systems that is flexible enough to be used in many types of facilities and does not require personnel with seismic expertise is the goal of this methodology.

Implementation of this goal is a multi-step process. Since the emphasis is on rapid assessment by the regular facility staff, the overall approach must remain simple, as described below:

1. **Systems Definition:** Requires input from appropriate facility operators and engineers to identify which systems are required for life-safety purposes and which systems are required for normal operations.

   For each system, graphically sketch the system process in a logic diagram, identifying critical components, system dependencies, and redundancies.

2. **Evaluation of Individual Components:** Perform a rapid visual screening inspection of each of the system components. Following the guidelines of the scoring system, a score is assigned to each item.

3. **Systems Evaluation:** Develop the scores for each subsystem and system in conjunction with the logic diagrams using the scores for the individual components. The logic diagrams will help to identify weak links in the systems, items that may need closer examination, or potential system vulnerabilities caused by lack of redundancy. Evaluate the scores for the individual components to identify weaknesses that affect functionality. Identify all vulnerabilities that may require some mitigation or further evaluation.

4. **Risk Management:** Use the results of the systems evaluation to make risk management decisions. This may include cost-benefit analyses to evaluate different options, additional evaluations to confirm screening evaluation findings, and assessment of emergency preparedness plans and other non-structural mitigations.

By following this approach, the operators of a facility can quickly gain useful insights into their seismic vulnerability. The logic diagrams and the scoring method show which systems are most vulnerable to seismically induced failure, which components in those systems are causing the vulnerability, and what remediation steps would be of most benefit to the overall system and facility earthquake preparedness.

This document summarizes the methodology. Part A is a Handbook, written as an instruction for users. Part B contains supporting documentation and technical bases for the approach. Part C is an example set of model code provisions utilizing this approach. Part C is intended to demonstrate how this approach can be incorporated into a format that can be used by designers or to evaluate existing facilities.

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SECTION 1

INTRODUCTION

1.1 Background

Recent earthquakes, the 1994 Northridge Earthquake in particular, have exposed shortcomings in current building design practices and design standards, especially with regards to damage that can shut down or limit services of a facility. Many facilities affected by the Northridge Earthquake were partially disabled, or entirely shut down, due primarily to non-structural and equipment failures in a wide variety of systems.

The methodology presented in this handbook was developed to provide a means of quickly assessing the reliability of a facility or system within a facility, with a focus on continued operation of the system or facility. There are two primary aspects to the overall approach that must be understood in applying this handbook. First, the approach is consequence based, incorporating the importance of individual equipment items in the reliability of a system. Second, the approach uses rapid visual screening techniques, and is intended to be used by people without expertise in engineering or seismicity. This handbook presents a scoring system with which the reviewer can quickly evaluate critical mechanical and electrical systems to determine which systems might warrant more detailed evaluation or modifications.

No engineering calculations or rigorous training are required to perform the reliability assessment. The guidelines presented in this handbook are intended to give a complete overview of the process and detailed descriptions of the steps involved in performing the review. The scoring system has been developed to limit the need for interpretation but still retain enough flexibility to be applicable to a broad range of installations and facilities nationwide.

In order to develop a screening process that can be performed rapidly by facility personnel on such a broad basis, a degree of conservatism is inevitable. Since this methodology is intended to provide broad estimates of a facility's vulnerability, a conservative approach is acceptable, and even desirable.

1.2 Personnel Qualifications and Training

This methodology was developed for use by non-technical people. All that is required is a knowledge of the systems to be evaluated and a thorough reading and understanding of this handbook. No formal training is envisioned for the process.

If several people at a given facility, or for several related facilities, will be implementing this process, some informal training may be in order. Since interpretations vary among individuals, pre-screening discussions will help to make the scoring more consistent among the various personnel. Though this methodology is intended to limit the amount of interpretation, it is always a good idea to make sure that everyone in a screening team has the same understanding of the process.

1.3 Organization of Handbook

The technical content of this handbook is organized in the following manner.

- Chapter 2 describes the overall general implementation of the program.
- Chapter 3 provides the procedure for identifying critical systems and components.
- Chapter 4 provides the procedure for evaluating individual components.
- Chapter 5 provides the procedure for combining results of assessments of individual components into subsystem and system scores.
- Chapter 6 discusses the interpretation of the results of the rapid visual screening survey and how to use the results in overall risk management for a facility.
- Appendix A includes checklists for use in systems identification.
- Appendix B contains detailed component worksheets.

SECTION 2

GENERAL IMPLEMENTATION

The following are the major steps involved in implementing the reliability assessment methodology using this handbook.

2.1 Step 1: System and Component Identification

What You Will Do:	*Look at what services your facility needs to provide, which equipment items and support services are really necessary to provide that function, and how the various items are tied together.*
How You Will Do It:	*Use checklists to help identify critical systems and components. Sketch logic diagrams to illustrate how systems are tied together and where you have backup system and equipment components.*
What This Does For You:	*Helps identify possible "weak links" in your system and ultimately helps to make sure fixes are limited to the most important items.*

A facility may have specific functionality requirements during or following an earthquake, as specified by federal law or federal, state, or local regulators. For example, hospital performance requirements for critical care may be specified in a state-issued license; data processing requirements for banks may be specified in Federal law. In addition, a facility owner may determine that a function is essential if it is deemed financially important for continued operation or business recovery.

A critical system is one that is required to provide either (i) the essential facility function, as defined above, or (ii) life-safety protection as required by other laws or regulations. A component of a critical system could be either a particular equipment item; a portion of a system such as piping, ducting, etc.; or a human action that is required to provide function of the critical system.

This handbook describes how critical systems and critical components can be identified for a facility. A method is provided for systematically reviewing important systems and the impact of their failure on other important systems. A means is provided to incorporate special considerations, such as emergency plans, personnel actions, and known maintenance problems.

Details are provided in Chapter 3.

2.2 Step 2: Assessment of Individual Components

What You Will Do:	*Assign "scores" to individual items indicating reliability to continue functioning after an earthquake. A higher score means more reliability.*

How You Will Do It:	*Do a mostly visual review of each component. Use data sheets in Appendix B to calculate scores. You will review for all items on the data sheets, assigning scores applying rules in this Handbook.*
What This Does For You:	*Helps identify weaknesses in individual equipment items.*

This handbook presents a method for rapidly evaluating individual equipment components and incorporating those evaluations into a system evaluation. That method uses assessment techniques based on historical earthquake performance of similar equipment items. Assessments are made of specific items that have been known to be causes of damage in past earthquakes, or known to be seismically vulnerable for other reasons.

Scoresheets are provided for individual components, and a method for assigning scores is presented, based on the design and installation of the component, the location within a building and geographically, and other factors. Higher scores indicate higher seismic reliability.

The method for assessment of components is provided in Chapter 4.

2.3 Step 3: Assessment of System Reliability

What You Will Do:	*Assign "scores" to systems and the entire facility indicating reliability to continue functioning after an earthquake. A higher score means more reliability.*
How You Will Do It:	*Use the scores from Step 2 with the graphical description of the system from Step 1. A set of simple rules to calculate the score is provided.*
What This Does For You:	*Provides the information you need to make decisions on what changes will increase reliability.*

This handbook provides a method for rapidly, but systematically evaluating the reliability of critical systems in an earthquake. A system scoring system is provided to quantify the relative reliability of systems and components. This method can be used by an individual to identify and prioritize vulnerabilities on a system and facility basis.

For each of the major systems identified, a system evaluation should be performed. The methodology described in this handbook makes use of the system and component information developed for each system and the scores for individual components.

The procedure for system scoring is described in detail in Chapter 5.

2.4 Step 4: Risk Management

What You Will Do:	*Make decisions about actual system modifications, more detailed analyses, or other steps to take (e.g. emergency plans) to increase the reliability of your facility operating following an earthquake.*
How You Will Do It:	*Use the results from Steps 1, 2, and 3. Review how scores may change if certain steps are taken.*
What This Does For You:	*This is the real reason for doing the entire assessment, to make sure that money spent for risk reduction is being put to its best use. This gives you a basis for deciding on various options, such as structural modifications, system changes, operational or procedural changes, or other reasonable ways of reducing risk.*

The results of the screening methodology provide a basis for making risk management decisions. The review of critical electrical and mechanical systems and their components provides the information necessary to create a specific plan for improving a facility's post-earthquake functionality.

The component and system evaluations described in this recommended practice are part of a screening assessment. It highlights important system components, their interactions, and their impact on system function. It is not the only indicator of where upgrades or repairs should be made, but it provides a consistent method for identifying obvious vulnerabilities and prioritizing risk management implementation.

Mitigation is not limited to physical repairs to equipment or systems. Mitigation can be achieved through means such as upgrades, analyses and emergency response procedures. All mitigation efforts as defined in this handbook are intended to improve overall system reliability.

More detailed discussion on risk management is provided in Chapter 6.

SECTION 3

IDENTIFYING SYSTEMS AND COMPONENTS

This chapter of the handbook describes the identification and documentation of critical systems and components which should be evaluated to assess the reliability of essential facility functions following an earthquake.

3.1 Facility Requirements

The owner of a facility should identify what the functional requirements of the facility are during and following an earthquake. Essential functions are those which must be provided by a facility during an earthquake, immediately following an earthquake, or within a specified time period following an earthquake. Examples may include requirements to provide emergency or critical care for hospitals or money transfers for banks. Other specific functionality requirements may be specified by federal law or federal, state, or local regulators.

Essential functions may be identified by any of the following means:

a) Specific facility performance requirements that are unique to a given facility, industry, or type of installation, may be specified by law or other regulatory or licensing requirements, under federal, state, or local jurisdiction.

b) Minimum standards of life-safety protection must be maintained irrespective of the event that has occurred and the level of escalation. This would include fire detection and alarm, fire response, building evacuation and egress, and similar systems or functions, as required by federal, state, or local laws and regulations.

c) A facility owner or manager may identify any additional function as critical and evaluate systems using this Recommended Practice because of financial considerations or any other reasons. Examples of such considerations would be concerns for capital costs, business interruption, and damage and recovery costs.

3.2 Identification of Critical Systems

As discussed above, critical systems are likely to include both life-safety systems and business operation systems. Life-safety systems are usually defined as those functions whose failure results in conditions where lives are in imminent danger or are not sufficiently protected from potential dangers. Typical examples of life-safety functions are:

a) Fire response (including detection, suppression, and smoke barriers/purge)

b) Shutoff of hazardous material releases (primarily natural gas)

c) Elevator safety

d) Evacuation/Egress

Business operation systems are defined as those systems which must function in order to continue operation of the facility at full or reduced capacity. This definition of capacity is the starting point for the identification of the critical business operation functions. For example, operation of elevators may be considered to be essential for full building operation in one situation but non-essential for another similar building if the desired state is limited operation. This designation depends on the essential function of the facility, and is determined as the first step of the evaluation. Typical examples of business operation functions are:

a) Lighting/Power (including lighting, normal building power, emergency power)

b) Water Supply/Waste Removal (including water supply, sewage removal)

c) Storm Drainage

d) Normal Personnel Transport (including elevators)

e) Building HVAC (including heating, ventilation, air conditioning, HVAC control)

f) Communications (including telephone/communications, data telecommunications)

g) Data Processing (including data processing equipment, computer equipment)

h) Refrigeration

i) Gas Supply

j) Structural Concerns (including raised access floors)

3.2.1 Critical Systems Checklist

Table 3-1 shows a multi-page checklist, the ***Critical Systems Checklist***, that can be used to identify and document systems which are candidates for critical systems. The reviewer should examine each system identified in the table (**Bolded** items in far left column) and make a determination as to whether the system is a life-safety system, business operation system, a non-critical system, or the system is not applicable to the facility in question.

If a system is determined to be critical (i.e., either a life-safety or business operation system) the evaluator should define what the critical system encompasses. This definition serves to identify both what is considered as success and to help establish the bounds of the evaluation. A space is provided in Table 3-1 for definition of the requirements for each critical system. The evaluator should make this definition as clear and concise as possible at this stage. For example, the definition for the Gas Shutoff System could read something like the following: "The gas shutoff system is required to close the gas shutoff valve, either manually or automatically, following the earthquake."

Table 3-1 also identifies sub-systems (indented items beneath each System) which serve to better define the boundaries of the main system. Each of these sub-systems should be examined and a determination made in the same manner as for the main systems. Additional spaces are included if other important systems or sub-systems are identified.

3.3 Identification of Critical Components

Functionality of the critical systems identified in the previous section is generally provided by operation of combinations of equipment and/or human actions. In some cases, a single operator action may be all that is required in order to provide for functionality, while in other cases the combined operation of several systems may be required. In some cases there may be redundant means for providing full or partial operation.

The goal of the entire process of identification of components is to narrow the scope of components examined from an all-encompassing list of building equipment to a list which reflects only those components necessary to provide functionality of critical systems while also accounting for any enhanced safety provided by installed redundancy. This section describes the method to be used to complete a systematic equipment identification process.

3.3.1 Component Identification Worksheet

One method for the identification of critical system equipment uses a worksheet called the ***Critical System Component Identification Worksheet.*** Table 3-2 is a general worksheet for one of the typical critical systems identified in Section 3.2. Appendix A provides additional worksheets for other systems listed in Section 3.2, as well as a blank worksheet to be completed if additional functions are identified or as a continuation sheet for any of the other worksheets. The types of information to be identified in each worksheet are discussed in detail below. In all the examples, Table 3-2 is referenced, but the discussion is equally applicable to any of the other tables.

1. **Definition of System:** The starting point for this identification of components is the refinement of the definition of what the critical system of interest encompasses and the specific performance requirements of that system. This definition serves to identify both what is considered as success and to establish the bounds of the evaluation. If the definitions established during the identification of critical systems are sufficient to accomplish these goals, a reference to the worksheet in Table 3-1 is all that is required. Otherwise, for each identified critical system, the definition should identify the following:

    a) The main system, systems or portion of systems which provide the required function

    b) The performance requirements and specific required functions of the items identified in item a) above (i.e., operation, integrity)

    c) How the function is provided (i.e., automatic or manual)

    d) When that function is required and for what duration

2. **Identification of Specific Components:** Once the system requirements are established, the reviewer then starts the task of identifying specific equipment which must function or maintain integrity in order to successfully accomplish the required system function. A component identification sheet, as shown in Table 3-2, will have a basic list of components typically associated with each sub-system. The reviewer should examine each item on the list and determine the criticality of each component. The categories of criticality are:

   a) *Essential (E).* Component is required to perform its function in order for the critical system to perform its required function (i.e., no other component can provide the same function)

   b) *Redundant (R).* Component is one of two or more components which can provide a function in order for the critical system to perform its required function (i.e., any redundant component can provide the same function)

   c) *Non-Essential (N).* Component is not required in order for the critical system to perform its required function. This category should also be used if a listed component is not installed in the system being examined.

   If a component is determined to be redundant to another component, the redundant component item number should be identified and listed in the appropriate column on the form. For example, in Table 3-2 under "A. Detection", any type of detectors which will result in the desired response (e.g., alarm, sprinkler actuation, etc.) should be identified as redundant to each other in the list.

3. **Support Requirements:** The final piece of component specific information necessary in the identification of essential components is the determination of support requirements, if any, for each piece of equipment. Support requirements generally deal with such functions as power, cooling water, or some types of actuation. The systems which provide these support functions are identified as support systems. In each of the critical system definition sheets, all of the components which provide the support functions could be added in their entirety and the overall resultant list of components would be correct. However this would result in a significant amount of repetition and is not efficient. Rather support systems should be added as a separate critical system (unless already required elsewhere as a critical system) and the support system components included on a "generic" form of Table 3-2. In addition, it should be cross referenced using Table 3-3, as described in Section 3.3.2 below.

   The one exception to this process is in the case where a support system or a certain portion of a support system only provides support to one critical system. In these cases, it is better to include it with its associated critical system. For example, an uninterruptible power supply (UPS), while considered to be a part of the electric power system, may only power a computer system. It can be considered a redundancy for the power requirements of the computer system but not for any other equipment which requires power. In this case the UPS should be listed with the specific equipment for the critical system and the electric power system identified as a support system.

4. **Other Considerations:** Two general items are important in determining the potential for equipment to reliably provide service as required. Questions associated with these general items are included for each sub-system on each sheet. The responses to these questions may impact whether or not a component is credited for the system functionality. These questions are:

   a) Is operator intervention required for operation of any of the above equipment? If yes, is the area expected to be accessible?

   b) Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures?

   For the first question, if operator action is required to operate the equipment, but the area is not likely to be accessible following an earthquake, the component should not be credited. If this piece of equipment is redundant to something else, this results in a loss of redundancy but not failure of the critical system. If however, this item is essential, the critical system would be considered to be failed by the earthquake and possible changes may be in order to provide some redundancy or to ensure accessibility.

   For the second question, if a component, system, or portion of a system has historically been unreliable due to failures or high maintenance requirements the reviewer may not want to include the component, system or portion of a system except as a redundancy. If components which fit in this category are to be credited, either as essential components or redundant components, the associated component score should be modified to account for the reduced reliability.

3.3.2 Support System Cross Reference Worksheet

In order to ensure that all support requirements are fully addressed, Table 3-3, ***Support System Component Identification Cross Reference,*** should be added to in conjunction with each ***Critical System Component Identification Worksheet*** (e.g. Table 3-2). Whenever a support function is identified to be required, the reviewer should add the support function to Table 3-3 including the definition and where it was identified. Once a ***Critical System Component Identification Worksheet*** has been completed for the particular support system, the reference should also be added to Table 3-3 wherever that support system is identified as being required. In this manner the reviewer can ensure that all appropriate components are included, and that support systems that are applicable to a number of other systems are only addressed one time.

3.4 Documentation

This section presents a recommended method for documentation of systems and components for use with this handbook.

3.4.1 *Critical Systems Diagrams*

These diagrams provide a pictorial view of the system interrelationships identified in the previous sections and provide a framework for quantifying the relative reliability of the systems following an earthquake using the methods described in Chapters 4 and 5 of this handbook. They are also a useful tool for the process of making practical risk management decisions, as discussed in Chapter 6.

The critical system diagrams are a type of logic tree which uses "AND" and "OR" logic to express the system interrelationships to the overall successful functioning of the building being examined. The following sections describe the method used to develop these critical system diagrams.

3.4.2 *Logic Trees*

The logic trees are success oriented and are built using "AND" and "OR" logic gates. An "AND gate is defined as being successful if all the inputs to the gate are successful. An "OR" gate is defined as being successful if any one of the inputs are successful. By combining these logic gates the reviewer can develop a model which accurately represents the critical system needs following an earthquake and can be used to identify the components which most critically affect the ability to provide these critical functions. All of the information necessary to build this logic model is collected as discussed in the previous sections. The development of the logic model should be completed in a step-by-step manner with each level of the logic tree being completed before proceeding to the next level. This methodical approach helps to ensure that all necessary functions and components are included and that the function and component dependencies are accurately addressed.

3.4.3 *Essential Functions*

The logic trees begin with a top event which represents successful functioning of the facility following an earthquake. This top event is labeled with the facility name and is an "AND" gate with two inputs, Life Safety Functions and Business Operations Functions. The "AND" gate implies that both functions must be provided in order for the successful provision of the critical functions. An example of this top level logic is shown in Figure 3-1. Each of these events represent a gate in the logic diagram and will be further developed in the manner discussed below either on the same page of the model or as a top event which is shown on another page. Care should be taken to ensure that if an event is developed on another page that there is a clear indication of where such development takes place.

If additional emphasis is desired for some other function such as Telecommunications Equipment or Data Processing Equipment they can also be included as a separate input to the "AND" gate rather than being included under one of the other items. By including them at this level, their overall importance is visually seen at the top level of the model. This positioning at the top level will not impact the results of the model evaluation. An example of two equivalent top level logic diagrams is shown in Figure 3-2. Each of these inputs to the top gate is developed further in a step-by-step process until the boxes placed under a gate represent components rather than functions.

3.4.4 *Critical Systems*

The next level of the logic model is developed from the information previously gathered and summarized in Table 3-1. For example, the systems which are marked as Life Safety in Table 3-1 become inputs to an "AND" gate in the top logic for Life Safety Functions. The systems which are marked as Business Operations in Table 3-1 become inputs to an "AND" gate in the top logic for Business Operations Functions. Again, these are both "AND" gates since each of the functions must be provided in order to successfully provide the required essential functions. In some cases in Table 3-1, a system may be listed as both a Life Safety and Business Operations system. In these cases the system should be included in both places. The lower level development of the logic will address any differences in sub-systems between the two locations. Any of the systems which include sub-systems should be represented as an "AND" gate with each of the applicable sub-systems as inputs. Figure 3-3 shows an example of the first input level to the Life Safety gate and the sub-system inputs for the Fire Response system gate.

3.4.5 *Specific Components*

Up to this point, all of the logic in the tree consists of "AND" gates since the primary focus has been on the function level and the basis of the definition of the functions has been to include only the essential functions. The remaining portions of the tree will define which components and in what combinations these components will adequately provide the functions. This is the level at which the concept of redundancy in design is generally implemented. It is this redundancy which leads to slightly more complexity in the modeling process. Worksheets such as in Table 3-2 identify the equipment necessary to provide the specific functions for that building.

For each sub-system there may be one or more categories of components. For example, in Table 3-2, Fire Response Sub-system Detection and Alarm is divided into three categories, Detection, Alarms, and Detection/Alarm Interface. If all three of these categories are required the Sub-system is an "AND" gate with each of these categories as an input. Within a category, all, one, or several of the listed components may be required for success.

The important equipment identified in these tables for each category have been previously defined in the table as being essential or redundant. In general, components which are categorized as essential are included as inputs to an "AND" gate which defines the category. If a category has only one essential component associated with it, a gate is not required and the equipment is shown as an input to the sub-system gate.

3.4.6 *Redundant Components*

If equipment is categorized as redundant, it and its redundant components are included as inputs to an "OR" gate which defines the category. The case may occur in which several of the components are essential and others are redundant. In this case the essential components are treated in the same manner as described above. In addition, a separate "OR" gate is added to the "AND" gate and the redundant components are input to the "OR" gate. Figure 3-4 illustrates the development of the fire Detection and Alarm sub-system logic.

3.4.7 *Support System Requirements*

These are identified in the tables in this chapter and are included at the level in the logic tree of the components it supports. An example of this is the case where a pump must system in order to provide fire water for fire suppression. In order to function, the pump must be provided with power. The way in which this dependency is included in the logic model is by including both the pump and its power supply as inputs to an "AND" gate at the same level as the pump would normally occupy.

The exceptions to this are if all components for a category require the same support system, or if a sub-system or system fail as the result of failure of the support system. In these cases it is acceptable to input the support system at the highest level in the logic model at which everything below it in the logic structure is also dependent upon the support system. Figure 3-4 shows an example of how support system requirements are included in the logic tree.

This process is repeated until logic models have been developed for each system/sub-system defined in the component identification worksheets prepared previously. Most support systems support multiple critical systems. The portion of the model associated with the support system need only be developed once and referred to at each place in the model in which it provides its support system.

3.5 Summary of System and Component Identification Procedure

The following is a summary of the steps outlined in this Chapter:

1. **Define the Facility Function:** Requires input from appropriate facility management to identify what functions or services the facility is required to provide during or following an earthquake, to satisfy legal requirements and owners desires.

2. **Identify Critical Systems:** Use the *Critical System Identification Checklist* (Table 3-1) or other means to identify critical systems and their functional requirements. The checklist provided in Table 3-1 includes common critical equipment systems.

3. **Identify Components and Sub-Systems:** Use the *Critical System Component Identification Worksheets* (Appendix A) for each system and subsystem to identify components and whether they are redundant, essential, or non-essential. Also identify supporting systems required and special considerations, such as operator intervention requirements and historical reliability problems. Appendix A contains separate worksheets for the typical systems identified on the checklist in Table 3-1, with typical components and sub-systems identified.

4. **Cross Reference Support Systems:** As each support system is identified on a *Critical System Component Identification Worksheet,* add that support system to the ***Support System Component Identification Cross Reference*** worksheet (Table 3-3) to identify and cross reference all of the required support systems. Complete a *Critical System Component Identification Worksheet* for each support system itself and add the reference for that sheet to the ***Support System Component Identification Cross Reference*** worksheet in each location that it appears.

5. **Document Systems and Components Using Logic Diagrams:** Use diagrams, such as Figures 3-1 to 3-4, to pictorially show system interrelationships and dependencies. The top level of these diagrams should be the essential facility functions identified in Step 1.

Table 3-1. Critical Systems Identification Checklist (1/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Fire Response	☐	☐	☐	☐
Requirements of system:______				
Sub-Systems				
Detection and alarm	☐	☐	☐	☐
Suppression	☐	☐	☐	☐
Air duct fire and smoke barriers	☐	☐	☐	☐
Smoke purge	☐	☐	☐	☐
Other:______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
Gas Shutoff	☐	☐	☐	☐
Requirements of system:______				
Sub-Systems				
Other:______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
Elevator Safety	☐	☐	☐	☐
Requirements of system:______				
Sub-Systems				
Detection/control	☐	☐	☐	☐
Other:______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
Building/Evacuation Egress	☐	☐	☐	☐
Requirements of system:______				
Sub-Systems				
Alarm/indication	☐	☐	☐	☐
Available routes	☐	☐	☐	☐
Other:______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐

Table 3-1 (continued). Critical Systems Identification Checklist (2/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Lighting/Power	☐	☐	☐	☐
Requirements of system: ____________				
Sub-Systems				
Lighting	☐	☐	☐	☐
Normal building power	☐	☐	☐	☐
Emergency power	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
Water Supply/Waste Removal	☐	☐	☐	☐
Requirements of system: ____________				
Sub-Systems				
Water Supply	☐	☐	☐	☐
Sewage Removal	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
Storm Drainage	☐	☐	☐	☐
Requirements of system: ____________				
Sub-Systems				
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
Normal Personnel Transport	☐	☐	☐	☐
Requirements of system: ____________				
Sub-Systems				
Elevators	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐

Table 3-1 (continued). Critical Systems Identification Checklist (3/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Building HVAC	☐	☐	☐	☐
Requirements of system:____________________				
Sub-Systems				
Heating	☐	☐	☐	☐
Ventilation	☐	☐	☐	☐
Air conditioning	☐	☐	☐	☐
HVAC control	☐	☐	☐	☐
Other: ________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Communications	☐	☐	☐	☐
Requirements of system:____________________				
Sub-Systems				
Telephone/communications	☐	☐	☐	☐
Data telecommunications	☐	☐	☐	☐
Other: ________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Data Processing	☐	☐	☐	☐
Requirements of system:____________________				
Sub-Systems				
Data processing equipment	☐	☐	☐	☐
Computer equipment	☐	☐	☐	☐
Other: ________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Refrigeration	☐	☐	☐	☐
Requirements of system:____________________				
Sub-Systems				
Other: ________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐

Table 3-1 (continued). Critical Systems Identification Checklist (4/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Gas Supply	☐	☐	☐	☐
Requirements of system: ______				
Sub-Systems				
Other: ______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
Structural Concerns	☐	☐	☐	☐
Requirements of system: ______				
Sub-Systems				
Raised access floors	☐	☐	☐	☐
Other: ______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
Other System: ______	☐	☐	☐	☐
Requirements of system: ______				
Sub-Systems				
______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
Other System: ______	☐	☐	☐	☐
Requirements of system: ______				
Sub-Systems				
______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐

Table 3-2. Fire Response Critical System Component Identification Worksheet

SYSTEM: FIRE RESPONSE

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Detection And Alarm

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Detection			
A.1 Area/Spot Smoke Detectors	E R N	________	________
A.2 Line Smoke Detectors	E R N	________	________
A.3 HVAC/Plenum Smoke Detectors	E R N	________	________
A.4 Heat Detectors	E R N	________	________
A.5 Sprinkler Flow Sensors	E R N	________	________
A.6 Pull Stations	E R N	________	________
A.7 Other(define)	E R N	________	________
________	E R N	________	________
B. Alarms			
B.1 Bell/Siren Alarms	E R N	________	________
B.2 Speakers	E R N	________	________
B.3 Strobe Lights	E R N	________	________
B.4 Remote Alarm Monitors (specify)	E R N	________	________
________	E R N	________	________
B.5 Other (define)	E R N	________	________
________	E R N	________	________
C. Detection/Alarm Interface			
C.1 Computer System	E R N	________	________
C.2 Fire Communication Center	E R N	________	________
C.3 Alarm Panel(s)	E R N	________	________
C.4 Cabling/Conduit	E R N	________	________
C.5 Other (define)	E R N	________	________
________	E R N	________	________

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table 3-2 (continued). Fire Response Critical System Component Identification Worksheet

SUB-SYSTEM: Fire Suppression

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Manual Suppression					
A.1 Hand Extinguishers	E	R	N		
A.2 Hose Stations	E	R	N		
A.3 Hose Station Water Supply (if different from Automatic System)	E	R	N		
A.4 Other(define)	E	R	N		
______	E	R	N		
B. Automatic Suppression - Water					
B.1 City Water Supply	E	R	N		
B.2 On-site Water Supply	E	R	N		
B.3 Motor-Driven Fire Pump(s)	E	R	N		
B.4 Diesel Driven Fire Pump(s)	E	R	N		
B.4.a Diesel Start System	E	R	N		
B.4.b Diesel Day Tank	E	R	N		
B.4.c Diesel Piping/Valves	E	R	N		
B.4.d Diesel Aux Fuel Supply	E	R	N		
B.5 Fire Water Feed Main	E	R	N		
B.6 Fire Water Cross Mains	E	R	N		
B.7 Fire Water Branch Lines	E	R	N		
B.8 Fire Water Risers	E	R	N		
B.9 Sprinkler Heads	E	R	N		
B.10 Deluge/Alarm Valves	E	R	N		
B.11 Other (define)	E	R	N		
______	E	R	N		
C. Automatic Suppression - Gas					
C.1 Gas Storage (Halon/Other)	E	R	N		
C.2 Connection to Detectors	E	R	N		
C.3 Other (define)	E	R	N		
______	E	R	N		

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

______

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

______

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table 3-2 (continued). Fire Response Critical System Component Identification Worksheet

SUB-SYSTEM: Air Duct Fire and Smoke Barriers

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Fire and Smoke Barriers			
A.1 Fire and Smoke Dampers	E R N	______	______
A.4 Other(define)	E R N	______	______
______	E R N	______	______

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ____
If yes, is the area expected to be accessible?

______

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ____
If yes, explain:

______

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Smoke Purge

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Detection			
A.1 Fire Control Center Panel	E R N		
A.2 Other(define)	E R N	______	______
______	E R N	______	______
B. Pressurization			
B.1 Fans	E R N	______	______
B.2 Actuation	E R N	______	______
B.3 Other (define)	E R N	______	______
______	E R N	______	______
C. Purge Pathway			
C.1 Break Window System	E R N	______	______
C.2 Other (define)	E R N	______	______
______	E R N	______	______

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ____
If yes, is the area expected to be accessible?

______

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ____
If yes, explain:

______

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table 3-3. Support System Component Identification Cross Reference

No.	Support Function	Description	Component Where Support System Identified	System Worksheet Used to Describe Support Function System
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

KEY		
SYMBOL	NAME	MEANING
	AND GATE	Component above gate functions if all components below function
	OR GATE	Component above gate functions if any component below functions

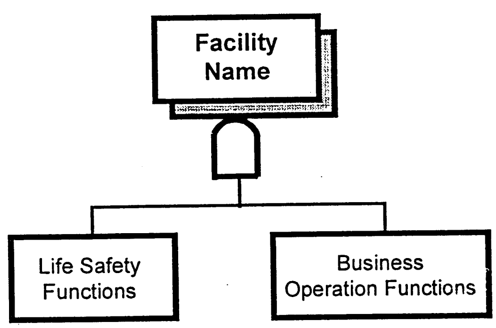


Figure 3-1: Facility Top Logic Model

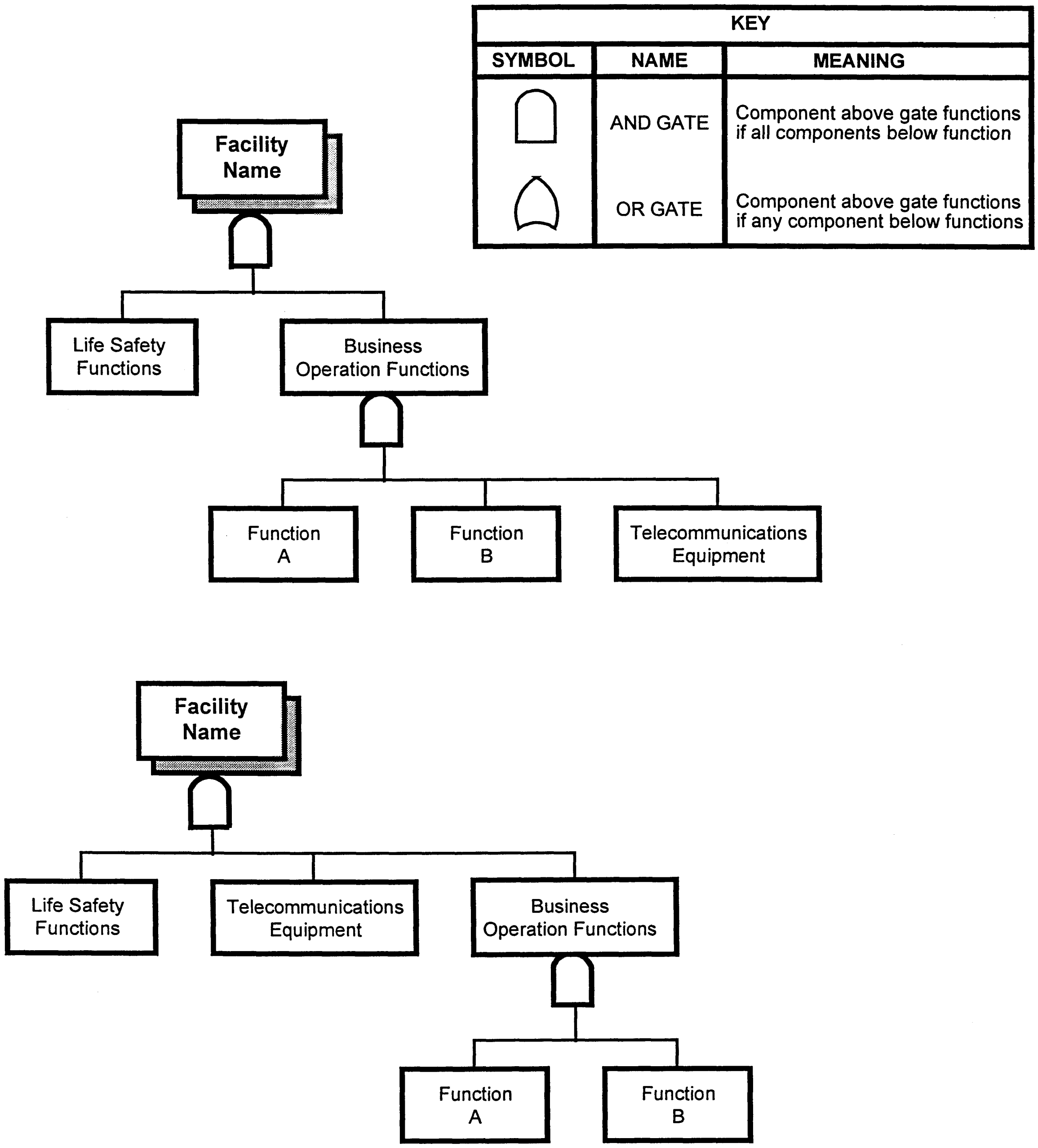


Figure 3-2: Equivalent Logic Model Configurations

KEY		
SYMBOL	NAME	MEANING
	AND GATE	Component above gate functions if all components below function
	OR GATE	Component above gate functions if any component below functions

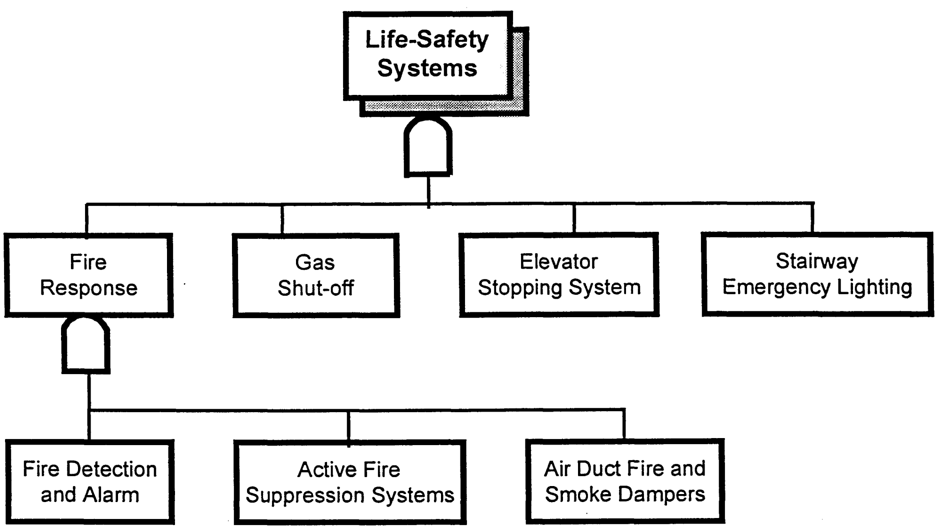


Figure 3-3: Life-Safety Systems/Fire Response Level Logic

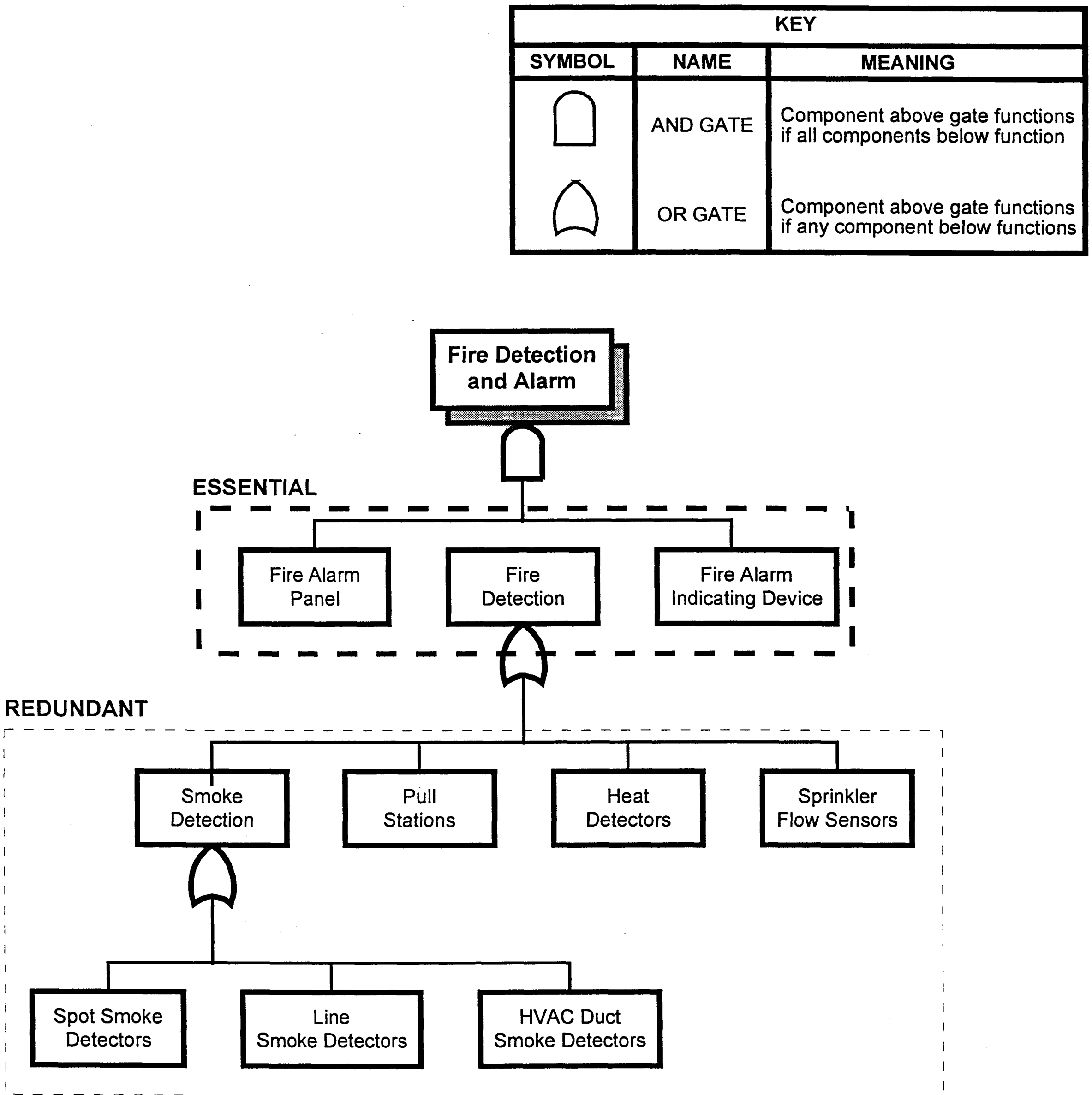


Figure 3-4: Fire Detection and Alarm Logic Example

SECTION 4

EVALUATING COMPONENTS

This chapter of the handbook describes the process of evaluating individual equipment system components. Data sheets, or score sheets, are to be filled out for each individual major equipment item or system, as appropriate. This section contains instructions for evaluating the items and assigning scores.

4.1 Required Information

Prior to performing the evaluation of components, the user should have certain knowledge and data about the facility and the systems being evaluated. The following should be considered a partial list of information that should have been gathered and compiled:

a) A list of components to be evaluated, as described in Section 3.

b) An understanding of the functional requirements of each component, as discussed in Section 4.2.

c) An understanding of the ground motion expected at the site, as discussed in Section 4.3. This could be in the form of standard hazard maps as used in building codes.

d) An understanding of the general soil conditions at the site. Specifically, the reviewer should determine if the facility is founded on very soft soils (e.g., Class S4 in the 1994 UBC, SF in the 1997 UBC, or Class F in the 1997 NEHRP provisions). This information should be available from a variety of sources, such as soil reports produced for building construction, from USGS maps, or from local agencies.

4.2 Understanding Functional Requirements for Components

This evaluation process uses *consequence-based* evaluations. It is crucial to understand that the intent of this process is not to ensure that every component meets a particular standard, such as a building code for new design. Rather, the primary goal is to ensure that the component has sufficient reliability so as to not cause the entire system or facility to shut down.

The scoring process used in this chapter assumes that every component is being checked for its ability to continue functioning *after* an earthquake. In some cases, this may require user intervention, such as resetting of relays or switches, or manual start. Those requirements should have been incorporated into the system identification process using Section 3 of this handbook.

An individual component may in fact have one of a number of performance requirements, such as:

a) Required to function during an earthquake

b) Required to function after an earthquake

c) Required to provide containment of materials (e.g. tanks)

d) Required to maintain position (no active function, but cannot move)

e) Required to maintain overall structural integrity (not collapse)

f) Combinations of the above

It is assumed throughout this process that the user has information or the ability to determine the functional requirements of each individual component. The user is expected to be able to determine the appropriateness and applicability of individual items on the score sheet, given those requirements. That may be especially true in those situations where functionality is limited to only a portion of a particular equipment item (e.g. a control panel). The person performing the review is expected to be able to judge whether or not specific items on the score sheet may be neglected.

4.3 Determining the Seismic Hazard at Your Site

Figure 4-1 shows an example data sheet for one type of equipment. The first step in component assessment is to identify the seismic load level that the component is expected to experience. This is a function of the regional seismicity, expressed in terms of the seismic zone, and the location in the building. The matrix in the data sheet is used to assign a load level classification to account for both of these features.

If your site is founded on very soft soils (e.g., Class S4 in the 1994 UBC, SF in the 1997 UBC, or Class F in the 1997 NEHRP provisions) the earthquake load level classification one level should be used that is one value more conservative than otherwise shown in the matrix. In other words, those facilities listed as D on the matrix should use the scores from column E. Those who are already listed at classification E would continue to use the "E" values.

Note that the determination of seismic zone need only be done one time for the entire facility, with the same zone used for all components. The location of the building should be determined for every equipment item. If unknown, the most conservative values will be for the upper portion of the building.

The following should be considered when using this matrix.

- Seismic zone refers to the classification applied by local regulating authorities to describe the seismicity at the facility location. These are generally found in model codes that are adopted by a locality, such as the *Uniform Building Code, Standard Building Code*, or *National Building Code*. The zones in the data sheets are referenced to the two most common zonations for the United States, from the *Uniform Building Code* (UBC), and the *Provisions from the National Earthquake Hazard Reduction Program* (NEHRP). The NEHRP provisions have been adopted by model code agencies and other industry standards and are now used in many parts of the country.

- If the individual has specific data on the site, such as site seismicity from a hazards analysis, that may affect seismic response of equipment components, that data may be incorporated into the component evaluation by a modification of the effective zone and seismic load level classification. To properly make such modifications, the individual should understand the derivation of those load level classifications.

- Location in the building is relative to the overall height of the building, measured generally in terms of lower 1/3, middle 1/3, and upper 1/3. Some judgment should be applied, such as considering the location of the attachment of the component to the building structure. The height of the building should be considered the height of the portion of the building containing the component, as measured from the top of foundation to the roof.

  For a single story building, items mounted on the floor will generally be considered to be in the lower 1/3, while items mounted from the ceiling will be considered to be in the upper 1/3.

4.4 Choosing the Correct Data Sheets

For each of the major system components identified as within the analysis scope, a component assessment should be performed. This method uses component data sheets, found in Appendix B.

A list of the data sheets provided in Appendix B is shown in Tables 4-1 and 4-2. These tables contain the same information, sorted alphabetically by component and by the classification used here.

Selection of the correct data sheets should be obvious for most major electrical and mechanical equipment items. However, data sheets have not been developed for every possible equipment item or configuration of equipment. Data sheets may also not be available for unique items that are specific to a given industry. In addition, particular industries may use certain equipment items that have been adapted to that industry in a way that could affect the response to earthquake loads. In selecting data sheets, the following should be considered:

- Equipment items should be considered similar to those on data sheets if they have the same general characteristics as that equipment and would be expected to respond in a similar manner to earthquake loading. The characteristics that should be considered include general construction, anchorage, mass distribution, typical size, typical aspect ratio (height to width), and functional requirements.

- The individual should be aware of differences in the equipment, especially with regards to reasons why the equipment being evaluated may be more sensitive to earthquake shaking than the equipment considered in the data sheets. This includes internal components, such as electrical subcomponents that may short out the equipment due to rocking, relays or switches that could cause the equipment to cease functioning, or control boards that can detach and slide. Any such differences should be identified, and documented as described in Section 3.6.

- The individual should also consider whether the design was similar for the component being evaluated and the typical components for which data sheets are provided. For example, the individual should determine whether the components are typically engineered for seismic loads, whether they are tested for shaking, whether they are sensitive to shaking in the frequency range typical of earthquakes, and whether anchorage is engineered for seismic loads.

- When using a different data sheet than provided for a specific class of equipment, the individual should assess the appropriateness of the modification factors, as described in Section 3.6, and make appropriate adjustments. For example, if the item being assessed is more sensitive to impact from falling objects than the data sheet component, that factor may be increased to account for that effect.

4.5 Performing the Assessment

4.5.1 Level of Detail

The method presented in this handbook is a *screening assessment*. It is intended for rapid use to identify obvious problems that require immediate attention and to prioritize potential upgrades and more detailed analyses. It is intended that the review will be primarily visual, although it may require a review of available drawings or specifications.

The data sheets used may not address every situation that might occur. They were developed to address weak links that have been proven to be causes of functional failure in past earthquakes.

It is also important to remember that the score sheets are intended only to help identify issues that will affect an items ability to function. They are not intended to identify all damage, such as dings and dents, if they don't affect the function.

4.5.2 Assigning the Basic Score

As shown in Figure 4-1, a basic score is provided for each of the load level classifications. The basic score in the appropriate column should be circled on the data sheet. This is generally considered to be a measure of the reliability of an item installed using "good" standard installation practices in a seismic region, including engineered anchorage. It generally does not include testing of components, or special seismic considerations other than the anchorage.

4.5.3 *Assigning Performance Modification Factors (PMFs)*

The Performance Modification Factor (PMF) is intended to be a measure of how much the reliability of an item will decrease under specific conditions.

As shown in Figure 4-1, several potential vulnerabilities have been identified for each general type of component, with PMFs assigned. The next step in the evaluation process is to identify which PMFs are applicable to the specific component being evaluated. The individual should use the column on the score sheet for the appropriate seismic load level classification, the same as used for the basic score.

The values assigned to **all** applicable PMFs should be circled in that column. It is critical that the evaluator not simply evaluate for the worst-case PMF and then stop the evaluation process. The scoring process uses the worst case, (i.e. largest) PMF to reduce the total score. However, if that value is changed because of additional information, upgrades to the equipment, or any other reason, the next largest PMF becomes the reduction factor, and so on.

When using the complete methodology of this handbook, the review of all PMFs is used in the Risk Management process, described in Chapter 6. It is important to understand a fix or modification to an item will increase the score, or whether other PMFs will then govern.

The following points should be considered when performing evaluations using the data sheets of Appendix C:

- Guidance is provided on the data sheet as to the intent of the PMF. If there is any doubt as to the applicability, the reviewer should circle the PMF so that it can be evaluated later in more detail.

- When lacking data due to inaccessibility, lack of drawings, or other reasons, the reviewer should make the most conservative assumptions with regards to identifying applicable PMFs. The reason for the conservative assumption should be noted on the data sheet so that those PMFs can be reassessed with better data if necessary.

- The PMFs identified during this phase of the evaluation can be changed or neglected later, as described in the risk assessment tasks of Chapter 6. Any unsubstantiated assumptions should be documented and reviewed for appropriateness and importance.

- Data sheets, such as in Figure 4-1, typically will have a PMF marked as "Other", without associated values or specific issues identified. This is a caution that it is impossible to cover all possible conditions with meaningful PMFs. For example, severely corroded connections on a component may lead the reviewer to question the capability of a component to survive earthquake loading. The user must exercise some judgment as to the amount of weight to put on each of these concerns and assign a value accordingly.

Although it is very difficult to assign PMFs without understanding where each number comes from, the user is expected to make his or her best estimate of the relative importance of other issues, compared with the items documented on the data sheets. Always remember that the intent is to address issues that affect the *function* of an item.

- It should be remembered that PMFs will always **reduce** the total score.

4.5.4 *Calculating the Total Component Score*

The total score for a component is calculated by subtracting the worst case PMF from the basic score. That value is then used in the systems analysis, as described in Chapter 5. The reviewer should note the following:

- Because all applicable PMFs have been identified, the total score is subject to change as more refined analyses are performed, upgrades are performed, or systems are modified, as discussed in Chapter 6. If it is determined that a PMF should be reduced, or neglected, the total score may be recalculated, subtracting the largest of the remaining applicable PMFs from the basic score.

- A relatively low component score does not necessarily indicate that an upgrade will be required. The systems analysis, as described in Chapter 5, is intended to account for the importance of the equipment item, system redundancies, and other factors in quantifying system reliability. However, the reviewer may identify obvious sources of low scores that can be easily and inexpensively modified, such as replacement of missing nuts and bolts, or anchorage of equipment. Those items should be identified for consideration in the risk management tasks of Chapter 6.

4.6 Summary of Procedure to Calculate Scores

The following is a summary of the steps outlined in this Chapter:

1. **Gather a List of Components to Be Evaluated:** Use the results from the evaluation performed in Section 3.

2. **Understand the Requirements of Each Component:** Make sure you understand what each item is actually required to do following an earthquake. We do not want to spend time and effort on the types of minor damage that do not affect an items ability to continue to perform its required function.

3. **Determine the Seismic Hazard at Your Site:** This is done one time for the entire facility. Use the building codes referenced in Section 4.3 of the Handbook.

4. **Choose the Data Sheet for Each Component:** Data sheets have been developed for major equipment items typically found in key systems in critical facilities. These sheets may not exactly cover each item. Tables 4-1 and 4-2 list typical components covered in those sheets. For other items, use similarity comparisons as discussed in Section 4.4 of the Handbook.

5. **Assign the Earthquake Load Level for the Component:** This considers that the actual shaking is a function of the seismic hazard at the site and the location in the building. An adjustment is made if your site is on very soft soils.

6. **Assign a Basic Score:** Use the earthquake load level from Step 5.

7. **Circle ALL PMFs that are Applicable:** Guidance is given as to the intent of each PMF on the data sheet. If it applies to the item you are evaluating, circle the PMF in the same column as the basic score (corresponding to the earthquake load level). Be sure to circle **all** PMFs that apply. Even though only the largest PMF is used (see Step 8 below), these sheets may be changed later if more detailed evaluations are done, or modifications are made and other PMFs may govern.

8. **Calculate the Total Score:** This is the Basic Score minus the largest circled PMF.

Table 4-1. Index of Components Included in Rapid Visual Screening Score Sheets (Sorted Alphabetically by Score Sheet Identifier)

Component	Score Sheet	Classification
Ductwork	DS-01	Distribution Systems
Piping (buried)	DS-01	Distribution Systems
Piping (above ground)	DS-02	Distribution Systems
Cable	DS-03	Distribution Systems
Cable Tray	DS-03	Distribution Systems
Conduit	DS-03	Distribution Systems
Motor Control Center	EL-01	Electrical Equipment
Switchgear	EL-02	Electrical Equipment
Transformer	EL-03	Electrical Equipment
Control Panel	EL-04	Electrical Equipment
Distribution Panel	EL-05	Electrical Equipment
Battery Rack	EL-06	Electrical Equipment
Battery Charger	EL-07	Electrical Equipment
Generator	EL-08	Electrical Equipment
Alarm (fire pull station)	FP-01	Fire Protection Equipment
Alarm (smoke, fire, heat)	FP-01	Fire Protection Equipment
Detectors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Monitors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Sensors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Dampers (smoke, fire)	FP-02	Fire Protection Equipment
Fire Extinguisher	FP-02	Fire Protection Equipment
Fire hose station	FP-02	Fire Protection Equipment
Valve (fuel shutoff)	FP-02	Fire Protection Equipment
Piping (fire protection)	FP-03	Fire Protection Equipment
Sprinkler Head	FP-03	Fire Protection Equipment
Fan	HV-01	HVAC Equipment
Air Handler	HV-02	HVAC Equipment
Chiller	HV-03	HVAC Equipment
Lighting (in suspended ceiling)	MB-01	Miscellaneous Building Components
Raised Access Floor	MB-01	Miscellaneous Building Components
Suspended Ceiling	MB-01	Miscellaneous Building Components
Elevator	MB-02	Miscellaneous Building Components
Elevator (derailment detector)	MB-02	Miscellaneous Building Components
Communications Control Equip.	MC-01	Miscellaneous Computer Equipment
Computer (mainframe)	MC-01	Miscellaneous Computer Equipment
Computer (micro, pc)	MC-01	Miscellaneous Computer Equipment
Computer (mini)	MC-01	Miscellaneous Computer Equipment

Table 4-1 (cont.). Index of Components Included in Rapid Visual Screening Score Sheets (Sorted Alphabetically by Score Sheet Identifier)

Component	Score Sheet	Classification
Computer (peripherals)	MC-01	Miscellaneous Computer Equipment
Document Handling Equipment	MC-02	Miscellaneous Computer Equipment
Media Rack	MC-02	Miscellaneous Computer Equipment
Medical Equipment (lab)	MD-01	Medical Equipment
Medical Equipment (unit)	MD-01	Medical Equipment
Refrigerators (blood bank)	MD-01	Medical Equipment
Generator (portable)	ME-01	Miscellaneous Electrical Equipment
Power Transfer Equipment	ME-01	Miscellaneous Electrical Equipment
Lighting (emergency stairway)	ME-02	Miscellaneous Electrical Equipment
Lighting (temporary)	ME-02	Miscellaneous Electrical Equipment
Pump	MN-01	Mechanical Equipment
Valve	MN-02	Mechanical Equipment
Compressor	MN-03	Mechanical Equipment
Cooling Tower	MN-04	Mechanical Equipment
Boiler	MN-05	Mechanical Equipment
Electrical Power (off-site)	OS-01	Off-Site Systems
Natural Gas (off-site)	OS-01	Off-Site Systems
Water, domestic (off-site)	OS-01	Off-Site Systems
Water, fire (off-site)	OS-01	Off-Site Systems
Cable Entrance Facility	TC-01	Telecommunications Equipment
Rack Mounted Components	TC-01	Telecommunications Equipment
Communications (microwave)	TC-02	Telecommunications Equipment
Communications (radio)	TC-02	Telecommunications Equipment
Communications (telephone)	TC-02	Telecommunications Equipment
Tank (on legs)	TK-01	Tanks
Heat Exchanger	TK-02	Tanks
Tank (horizontal)	TK-02	Tanks
Tank (vertical, anchored)	TK-03	Tanks
Drum	TK-04	Tanks
Tank (vertical, unanchored)	TK-05	Tanks

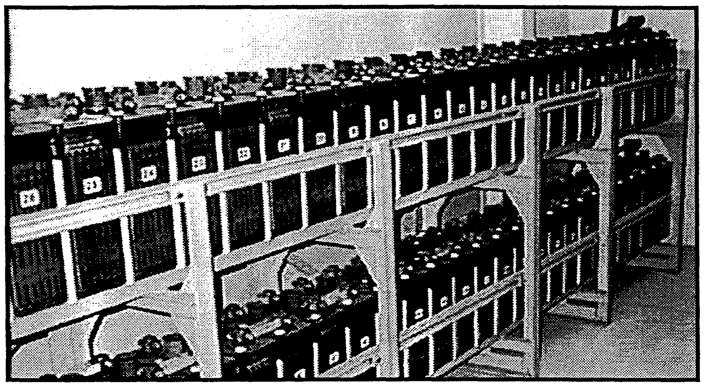
Table 4-2. Index of Components Included in Rapid Visual Screening Score Sheets (Sorted Alphabetically by Component)

Component	Score Sheet	Classification
Air Handler	HV-02	HVAC Equipment
Alarm (fire pull station)	FP-01	Fire Protection Equipment
Alarm (smoke, fire, heat)	FP-01	Fire Protection Equipment
Battery Charger	EL-07	Electrical Equipment
Battery Rack	EL-06	Electrical Equipment
Boiler	MN-05	Mechanical Equipment
Cable	DS-03	Distribution Systems
Cable Entrance Facility	TC-01	Telecommunications Equipment
Cable Tray	DS-03	Distribution Systems
Chiller	HV-03	HVAC Equipment
Communications (microwave)	TC-02	Telecommunications Equipment
Communications (radio)	TC-02	Telecommunications Equipment
Communications (telephone)	TC-02	Telecommunications Equipment
Communications Control Equip.	MC-01	Miscellaneous Computer Equipment
Compressor	MN-03	Mechanical Equipment
Computer (mainframe)	MC-01	Miscellaneous Computer Equipment
Computer (micro, pc)	MC-01	Miscellaneous Computer Equipment
Computer (mini)	MC-01	Miscellaneous Computer Equipment
Computer (peripherals)	MC-01	Miscellaneous Computer Equipment
Conduit	DS-03	Distribution Systems
Control Panel	EL-04	Electrical Equipment
Cooling Tower	MN-04	Mechanical Equipment
Dampers (smoke, fire)	FP-02	Fire Protection Equipment
Detectors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Distribution Panel	EL-05	Electrical Equipment
Document Handling Equipment	MC-02	Miscellaneous Computer Equipment
Drum	TK-04	Tanks
Ductwork	DS-01	Distribution Systems
Electrical Power (off-site)	OS-01	Off-Site Systems
Elevator	MB-02	Miscellaneous Building Components
Elevator (derailment detector)	MB-02	Miscellaneous Building Components
Fan	HV-01	HVAC Equipment
Fire Extinguisher	FP-02	Fire Protection Equipment
Fire hose station	FP-02	Fire Protection Equipment
Generator	EL-08	Electrical Equipment
Generator (portable)	ME-01	Miscellaneous Electrical Equipment
Heat Exchanger	TK-02	Tanks
Lighting (emergency stairway)	ME-02	Miscellaneous Electrical Equipment
Lighting (in suspended ceiling)	MB-01	Miscellaneous Building Components
Lighting (temporary)	ME-02	Miscellaneous Electrical Equipment

Table 4-2 (cont.). Index of Components Included in Rapid Visual Screening Score Sheets (Sorted Alphabetically by Component)

Component	Score Sheet	Classification
Media Rack	MC-02	Miscellaneous Computer Equipment
Medical Equipment (lab)	MD-01	Medical Equipment
Medical Equipment (unit)	MD-01	Medical Equipment
Monitors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Motor Control Center	EL-01	Electrical Equipment
Natural Gas (off-site)	OS-01	Off-Site Systems
Piping (above ground)	DS-02	Distribution Systems
Piping (buried)	DS-01	Distribution Systems
Piping (fire protection)	FP-03	Fire Protection Equipment
Power Transfer Equipment	ME-01	Miscellaneous Electrical Equipment
Pump	MN-01	Mechanical Equipment
Rack Mounted Components	TC-01	Telecommunications Equipment
Raised Access Floor	MB-01	Miscellaneous Building Components
Refrigerators (blood bank)	MD-01	Medical Equipment
Sensors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Sprinkler Head	FP-03	Fire Protection Equipment
Suspended Ceiling	MB-01	Miscellaneous Building Components
Switchgear	EL-02	Electrical Equipment
Tank (horizontal)	TK-02	Tanks
Tank (on legs)	TK-01	Tanks
Tank (vertical, anchored)	TK-03	Tanks
Tank (vertical, unanchored)	TK-05	Tanks
Transformer	EL-03	Electrical Equipment
Valve	MN-02	Mechanical Equipment
Valve (fuel shutoff)	FP-02	Fire Protection Equipment
Water, domestic (off-site)	OS-01	Off-Site Systems
Water, fire (off-site)	OS-01	Off-Site Systems

Rapid Visual Screening Score Sheet	EL-06



Batteries and Racks

ID Number ____________________

Comments ____________________

____

____

____

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Batteries and Racks

(circle a Basic Score and all PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**6.0**	**5.5**	**5.1**	**4.6**	**4.2**
	1. No anchorage	2.2	2.2	2.2	2.2	2.2
	2. "Poor" anchorage	2.0	2.0	2.0	2.0	2.0
P	3. No battery spacers	2.2	2.2	2.2	2.2	2.2
M	4. No longitudinal cross-bracing	2.0	2.0	2.0	2.0	2.0
F	5. No battery restraints	2.4	2.4	2.4	2.4	2.4
	6. Interaction concerns	2.4	2.4	2.4	2.4	2.4
	7. Other____________					
Final Score = Basic Score - **highest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Figure 4-1: Battery Score Sheet

Performance Modification Factors (PMFs)

1, 2 If there are no anchor bolts at the base of the frame, select PMF 1. If the anchors appear to be undersized, if there are not anchors for every frame of the rack, or if the anchorage appears to be damaged select PMF 2.

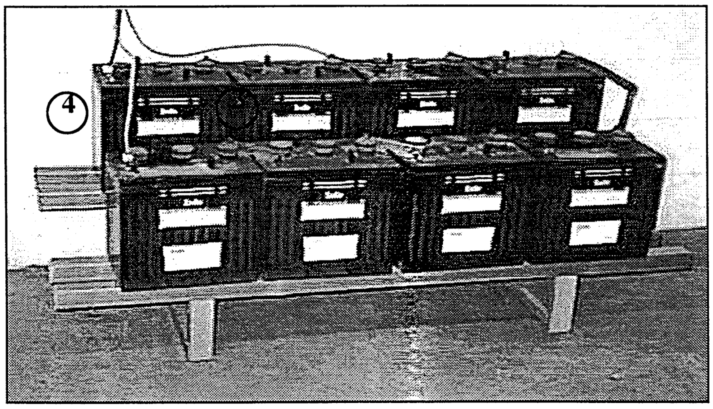
3 Look for stiff spacers, such as Styrofoam, between the batteries that fit snugly to prevent battery pounding. If there are none, select PMF 3.

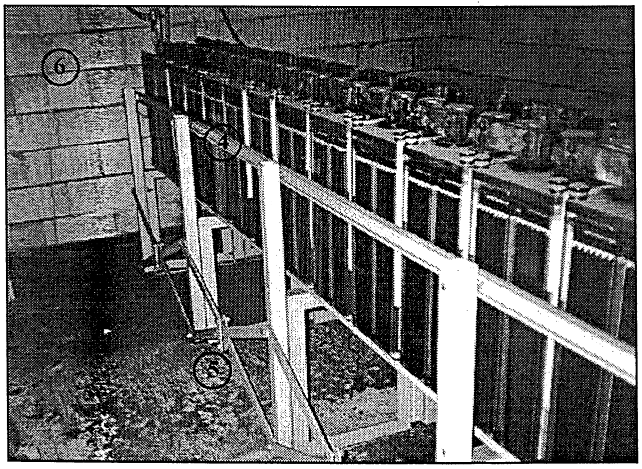
4 The rack should provide restraints to assure that the batteries will not fall off. The top photo shows a rack with no restraints, while the photo to the left shows a rack with restraints. Select PMF 4 if adequate restraint is not provided.

5 Racks with long rows of batteries need to be sufficiently stiff or braced longitudinally as shown in the photo to the left. Select PMF 5 if no cross-bracing is present.

6 If large items such as non-structural walls could fall and impact the battery racks, select PMF 6.

7 For other conditions that the reviewer believes could inhibit battery function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





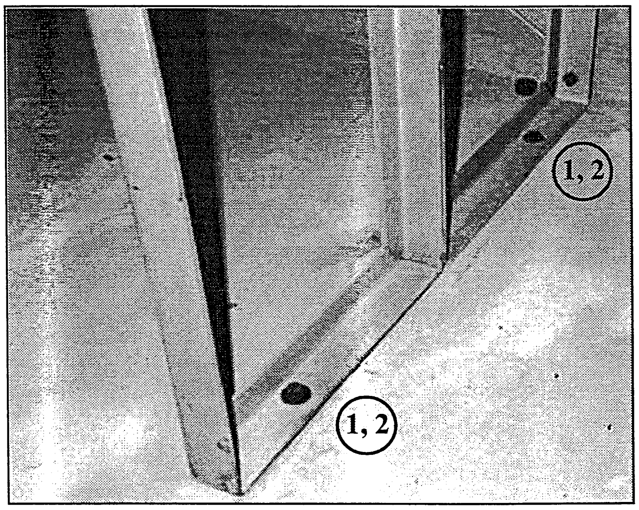


Figure 4-1: Battery Score Sheet (cont.)

SECTION 5

EVALUATING SYSTEMS

This chapter of the handbook describes the process of evaluating systems. Data sheets, or score sheets, will have been filled out for each individual major equipment item or system, using the data sheets provided in Section 4 and Appendix C. This section contains instructions for evaluating the systems and assigning scores. This method can be used for an individual system or for an entire facility.

5.1 Required Information

Prior to performing the system evaluation, the user should have the following information available:

a) A list of components with system relationships described graphically, as described in Section 3.

b) Scores for each component, using the methods of Section 4.

5.2 Background

This chapter describes a simple, standard method of generating system scores based on component evaluations. This method is not intended to give a mathematically rigorous and precise calculation of system reliability. Rather, it is intended to use straightforward rules to give reasonable estimates of the system reliability.

The supporting documentation for this handbook provides more detail regarding the derivation of this scoring method.

5.3 Types of Systems

The logic trees used to describe the system will describe system dependencies in one of two ways, either using an "AND" gate, or an "OR" gate. Users familiar with detailed risk analyses will recognize that there are several other options that can actually be used to describe component dependencies; however, they are considered to be much too complex for use in this methodology.

The following paragraphs, along with the figures of Section 5, describe these ways of defining the system.

5.3.1 Redundant Systems

The ability of a system to perform its function despite the failure of one or more components indicates redundancy in the system. This is a key element in the methodology described in this recommended practice. Although damage to a system is not desirable, it may not require mitigation if redundancy is present.

The "OR" gate represents a redundant path, where as long as either component A **or** component B is functioning, the system will continue to function.

5.3.2 Dependent Systems

A dependent system, or portion of a system, is a situation where failure of any one item will cause the entire system to fail.

The "AND" gate represents a dependent path, where both component A **and** component B must function for the system to continue to function.

5.4 Rules for Calculating System Scores

5.4.1 General Rules

The system diagrams developed according to the guidelines in Chapter 3 are used as the score sheets for their respective systems. System scores are calculated as follows:

- Assign the component score determined using the guidelines in Chapter 4 to the appropriate box on the system diagram. An example is shown in Figure 5-1.

- System scores are calculated by following the system diagram from the bottom to the top. The "and" and "or" gates indicate how the individual component scores are combined as the reviewer moves up the diagram. The final score for the system is the combination of all the individual component scores following the rules of this section and is recorded in the box at the top of the diagram.

- In figure 5-1, all components connected to the "and" gate under the right hand branch of "Water Pumps" are required to function, so that path is dependent. Only one of the components connected to an "or" gate, such as under "Water Supply" is required to function, so that path is redundant. Note that in this example, there are several "nested" branches that are both redundant and dependent. Each branch, or set of boxes, under a given gate should be considered separately and have a number assigned.

Rules for combining component scores in dependent and redundant systems are described below.

5.4.2 *Rules for Redundant Systems*

When a group of components is linked by an "**or**" gate (indicating redundancy), the recommended overall score for that group is the highest of the component scores (S_{max}) plus a factor (f). This factor depends on the number of redundant components (N) and takes the form: $f = 0.5(N-1)$. Thus, the score for a redundant group of components is: $S_{max} + 0.5(N-1)$. See Figure 5-2 for an example.

5.4.3 *Rules for Dependent Systems*

When a group of components is linked by an "**and**" gate (indicating dependency), the recommended overall score for that group is the lowest of the component scores, S_{min}. See Figure 5-3 for an example.

5.4.4 *Special Considerations*

System reliability can be affected by circumstances, such as requirements for operator actions (e.g. reset of relays), inaccessibility to components and controls, or general reliability (e.g., a history of maintenance problems with a piece of equipment). These factors may have already been addressed during the system identification described in Chapter 3. They will have an effect on the risk management portion of this assessment, as described in Chapter 6. Any special considerations related to system function should be noted so they can be evaluated and addressed as part of the risk management implementation.

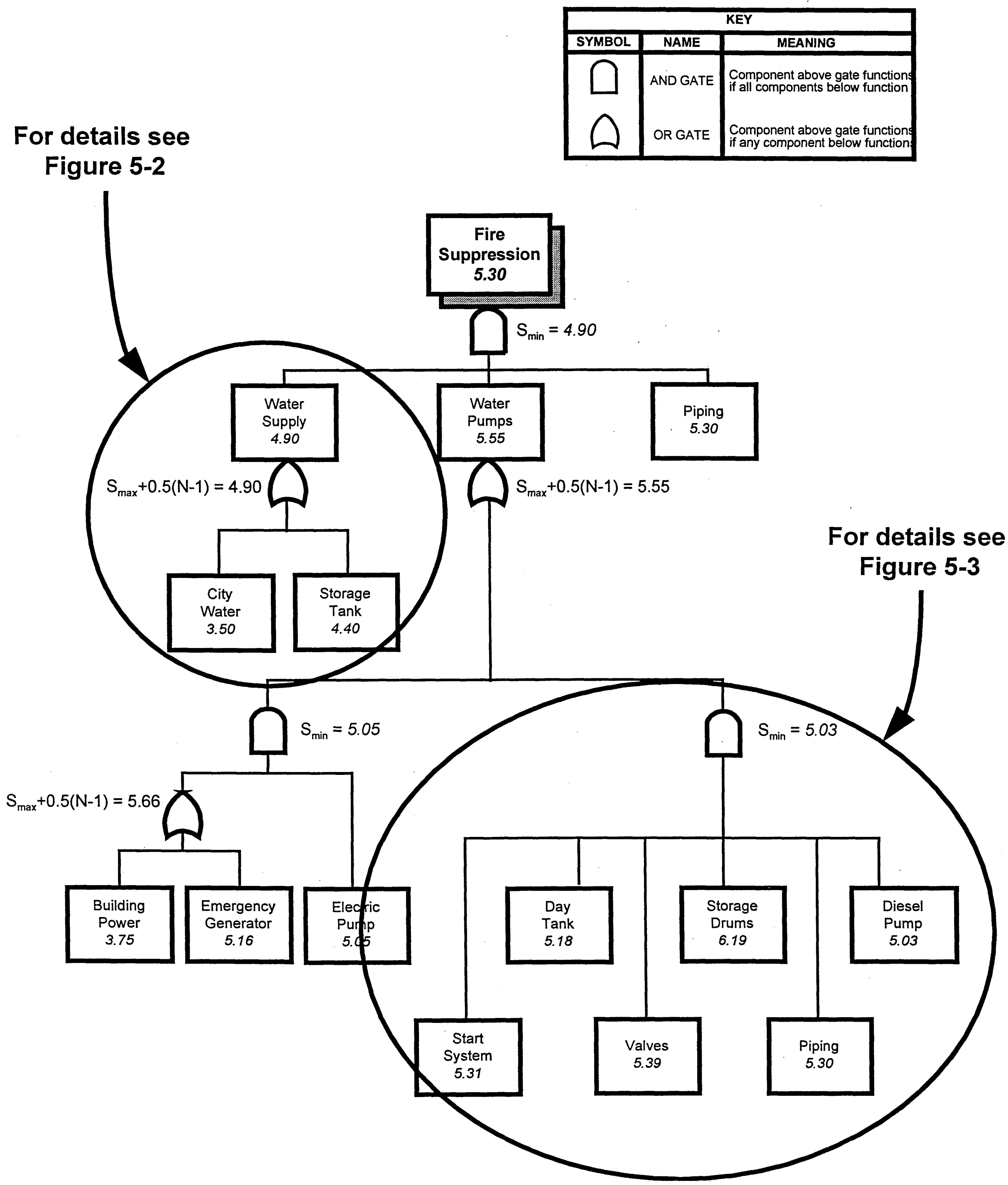
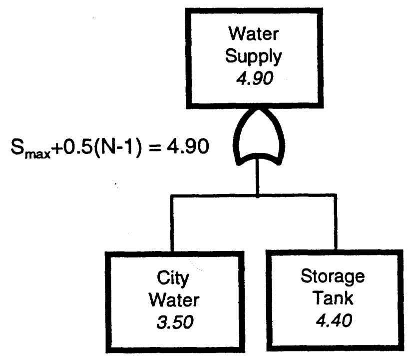
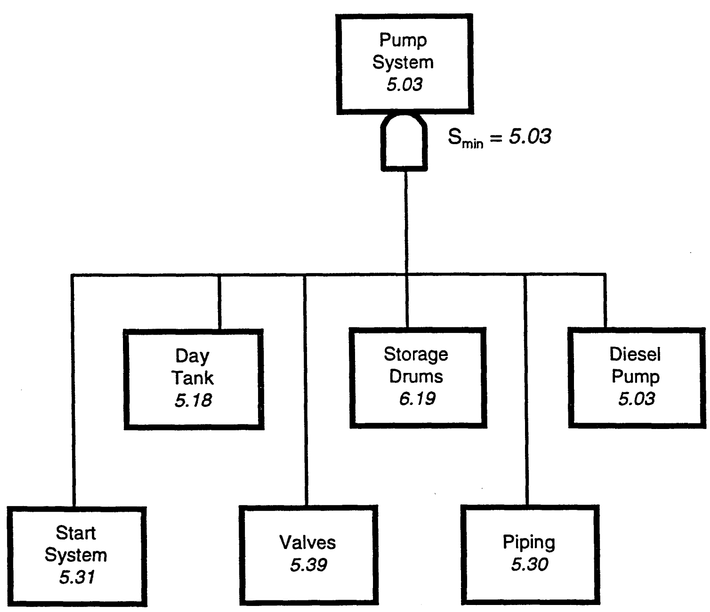


Figure 5-1: Illustration of system scoring
Numbers shown were selected for illustrative purposes only.



The water supply can be provided by either an on-site storage tank or a connection to the municipal water supply. The score for this redundant subsystem is dependent on the number of redundant components (N = 2) and the highest component score (S_{max} = 4.40). The formula to calculate the water supply score is shown above.

Figure 5-2: Sample Redundant System



The pump system will not function unless all its components function. The score for this dependent system is controlled by the lowest component score. In this case the diesel pump (S = 5.03) is the controlling component.

Figure 5-3: Sample Dependant System

SECTION 6

RISK MANAGEMENT

6.1 Background

Previous sections of this handbook have described how to identify systems and components and perform evaluations. After these evaluations are made, the results must be interpreted correctly if reasonable decisions are to be made. This chapter discusses issues related to that decision making process.

6.2 Required Information

The review of critical electrical and mechanical systems and their components provides the information necessary to create a specific plan for improving a facility's post-earthquake functionality. To accomplish this, information from the earlier portions of this program are used as follows:

- Results of the systems evaluation are used to identify which systems constitute potential weaknesses in overall facility reliability, and which components constitute weaknesses in each system's reliability.

- Results of component evaluation are used to determine causes of low reliability of those components identified in the previous step.

With this information, an action plan can be developed to mitigate risks to an acceptable level. It must always be remembered that the action plan does not require fixing all "problems" or "deficiencies" that were identified during the component review. If they do not affect the functionality of the system, they may be considered to be acceptable.

6.3 Philosophy

Risk is generally considered to be a measure of human injury or economic loss in terms of both likelihood (frequency) and the magnitude of loss or injury (consequences). In the process outlined in this handbook, the measure of risk is presented in terms of a score. A larger score indicates less risk and higher reliability.

This entire process is intended to be performed as a screening assessment. It is intended to highlight important system components, their interactions, and their impact on system function. It is not intended to be the only indicator of where upgrades or repairs should be made. Rather, it should be considered to provide a consistent method for identifying obvious vulnerabilities and prioritizing potential risk mitigation measures.

Acceptance criteria are established by facility operators and owners, or local governing regulating agencies, as appropriate. When one of the intentions of risk management is to satisfy regulatory requirements, then all systems are compared to the acceptance criteria. Those systems that do not meet the criteria can be addressed using one of the mitigation strategies described below

6.4 Risk Management Implementation

Risk mitigation is not limited to physical repairs to equipment or systems. Mitigation can be achieved through means such as upgrades, analyses and emergency response procedures. Risk management is the process of assessing various mitigation options and selecting appropriate measures

Figure 6-1 shows the overall process of implementing risk management. The main steps of the overall implementation process are as follows:

1. **Acceptance Criteria.** A score has been calculated for each critical system identified and reviewed during the screening process. Each system should be ranked using these scores so that the highest risk systems (lowest scores) are assigned as the highest priority. Examples of suggested risk categories to be used for acceptance criteria are presented in Table 6-1.

2. **Identify and Review Controlling Components.** For every critical system, the component(s) causing the "low" system score should be identified. These critical components should be reviewed in more detail. The first step is to verify that the basic score and modifiers were correctly applied during the screening process. Ensure that there is no additional information available that could be included to reduce conservatism of the original analysis. An action plan should then be developed to mitigate the vulnerabilities. It is import to address all vulnerabilities that could would cause the system score to not meet the acceptance criteria, not just the "worst case" vulnerability, i.e. the highest assigned PMF, identified during the screening process.

3. **Identify Mitigation Strategies.** As part of an action plan, one or more of the following methods may be used to increase the calculated reliability of critical components. They are discussed in more detail in Section 6.6.

   - *Perform detailed analyses* - This is used to demonstrate a greater reliability for the component than was previously estimated. It can result from different analysis techniques, or the consideration of additional data made available.

   - *Upgrade the component* - This can include repairs, replacement or modification of the component.

   - *Modify the system* - This can be used to bypass the critical component so that it will not adversely affect system function, or to add redundancy to increase reliability of the system.

   - *Identify other reasonable means or justification.* - This would usually involve an emergency response plan or similar document, and could include procedures for manual intervention to prevent system failure after a seismic event or replacement of damaged equipment with spare parts. These types of justification should be reviewed carefully on a case-by-case basis.

4. **Emergency Preparedness Plan.** After identifying means to achieve desired risk reduction in all critical systems, it is highly recommended that the emergency response plan should be reviewed for each facility. Section 5.6 discusses considerations for this process.

6.5 Acceptance Criteria

The screening process provides results that are useful in ranking systems and components relative to each other. Overall system reliability indicators of critical systems may need to also be compared to acceptance criteria to determine whether mitigations are necessary. An example acceptance criteria is presented in Table 6-1.

Note that in this handbook, specific pass/fail acceptance criteria are not used. The numbers in table 6-1 are examples only. The supporting documentation manual for this handbook provides a reference (Porter, et.al., 1997) and some discussion on how these criteria can be developed.

When acceptance criteria are used with this handbook, the following considerations should be incorporated:

- It should be noted that these acceptance criteria are to be applied to the systems to address system functionality after an earthquake. They are not intended to provide acceptance criteria for individual components.

- Scores which are lower than the governing acceptance criteria may be justified. In those cases, caution should be used to ensure that unsubstantiated assumptions are not made in the justification process.

6.6 Mitigation

There are many strategies available to reduce the risk present in a component, a system or a facility. This section discusses several methods of mitigating specific items.

For example, using the acceptance criteria and classification of Table 6-1, mitigation would be required for all vulnerabilities that could cause the component to fall into the "high" or "very high" risk categories. There may be multiple vulnerabilities present in a system or in an individual component that would result in such an unacceptable classification. An action plan may involve implementing more than one of the mitigation strategies described below.

1. **Perform Detailed Analyses.** Additional analyses can provide more specific details on whether vulnerabilities can be reduced or eliminated altogether. Examples of detailed analyses include the following:

- *Additional Screening Review of Specific Vulnerabilities.* The screening process provides a first look at a piece of equipment or a system. During this process a large number of items are reviewed and some details may not be recorded or may be missed. A reasonable analysis approach should include reassessing the smaller list of important vulnerabilities identified for critical components. This additional review may be performed by engineering personnel.

- *Incorporation of Additional Data.* As appropriate, reassess each important vulnerability identified during the screening process, incorporating data not available during the screening process. For example, where equipment anchorage or the attachment of internal components could not be accessed, additional data may be available from drawings or from opening up equipment to inspect anchor bolts, welds, or attachments.

- *Anchorage or Load Path Review.* Screening assessments may identify anchorage or the equipment load path as the controlling vulnerability. More detailed analyses may include specific calculations of capacity and comparison to seismic loads. These would generally be performed in conjunction with the governing seismic code, as specified by the regulating agency.

- *Systems Interaction Review.* Screening assessments may identify vulnerabilities associated with equipment displacement or impact as the most important. Example calculations to address these issues would be verification of anchorage, or determination of relative displacements and comparison to separations or comparison of resulting stresses to allowable stresses. Codes or accepted industry standards, as appropriate, should be used to determine whether results are considered acceptable.

- *Equipment Specific Concerns.* The screening process may identify concerns for specific components that are related to unique details, configurations, or other concerns that are difficult to address through typical structural calculations. Options for further analysis would include shake table testing or comparison to tests of similar components or a detailed review of the historic performance of the specific equipment type should be performed to demonstrate its acceptability.

2. **Upgrade Components.** Whether demonstrated by detailed analyses or determined to be appropriate based on inspection, some items require repair or replacement to mitigate a vulnerability. The use of one or more of these options should be determined based on the most efficient risk reduction available.

   - *Repair or Modification.* As appropriate for the component, a vulnerability may be mitigated by repairing or modifying its operation, configuration, construction, or other structural details. Repairs or modifications should not compromise any safety features of the system or component or cause it to operate outside its normally accepted limits.

- *Replacement.* As appropriate for the component, a vulnerability may be mitigated by replacement. All replacement items should provide performance equal to or better than the original component and provide an acceptable risk ranking.

3. **Modify System.** Whether demonstrated by detailed analyses or determined to be appropriate based on inspection, some systems may require modification to mitigate a vulnerability. The use of one or more of these options should be determined based on the most efficient risk reduction available.

   - *Redundancy.* As appropriate for the component, a vulnerability may be mitigated by installing a redundant component or pathway. For maximum benefit the redundancy should be capable of providing the same or better functionality to the system without use of the vulnerable component.

   - *Bypass.* As appropriate for the component, a vulnerability may be mitigated by bypassing the vulnerable component or pathway using physical or procedural controls. No bypass should compromise any safety features of the system or component or cause it to operate outside its normally accepted limits.

4. **Identify Other Reasonable Means of Justification.** This could involve any of the following:

   - *Demonstration of adequate emergency plan.* A facility may have an emergency plan that considers earthquake effects and the critical facility functions. It is possible that system failures may be accommodated by other means, such as using other corporate facilities, using spare inventory for a designated time, etc. Section 5.6 discusses several considerations for reviewing these types of plans to ensure appropriate applicability.

   - *Identification that manual intervention can be utilized.* In some instances, operators will identify that manual intervention is acceptable for specific vulnerabilities, such as reinsertion of circuit boards that may become dismounted. If such an action is used for justification, the appropriateness again should be carefully reviewed. Several items should be verified, such as whether the operator or other qualified personnel are available to perform that function at all times, whether specially trained personnel are required, whether the equipment is easily accessed, or whether other utilities (e.g. power, water, etc.) are required for the operator to perform the function. This justification should be carefully considered to ensure that any similar concerns are addressed.

   - *Availability of spare parts or equipment.* A low system score may be justified if the particular components resulting in the low score can be easily repaired within an acceptable time frame and spare parts and equipment are kept in stock. Again, several issues should be carefully reviewed, such as whether the spare parts are readily accessible, whether trained personnel are required and available, whether other services (e.g. power) are required to perform the necessary repair or replacement. This justification should be carefully considered to ensure that any similar concerns are addressed.

6.7 Emergency Response Plan

1. **General.** An Emergency Response Plan (ERP) is a set of procedures that provide a method of addressing the most critical functions of emergency response and recovery for a facility. Among other things, an ERP typically contains:

- Emergency authorization to activate and conduct operations.
- An organized management system for response and recovery operations.
- A methodology for gathering and evaluating information on the emergency.
- An organized system for providing information and coordinating response to the local community and authorities.
- An organized system for the early procurement and allocation of resources.
- A methodology for assessing damage and the operation of the facility.
- Procedures and policies to address loss of communications.

An ERP does not supersede existing procedures such as those for handling medical emergencies or hazardous materials release. It is meant to supplement those procedures with a cohesive temporary management structure that provides immediate management of response during the period following a major crisis. The plan is activated whenever conditions exist that prevent normal operations from being performed and immediate action is required to save lives, prevent damage to property and restore operations.

1. **Earthquakes.** To address earthquakes properly an ERP, or an assessment supporting an ERP, must consider realistic scenarios that may occur in a moderate or a major event. Examples of earthquake specific concerns are:

- Transportation systems (e.g., roadways, railroads, etc.) may be unusable or severely restricted.
- Buildings and structures may be damaged.
- Multiple systems may be lost during a single event.

- Personnel response is unpredictable and may also be hindered by limited access to equipment and controls.
- Parts needed for repairs may not be readily available.
- Experienced personnel required to perform emergency operations may be unavailable.

2. **Use of ERP for Mitigation.** Part of this recommended practice allows the use of ERP procedures to mitigate certain vulnerabilities. When assessing an ERP for this function, the following should be considered:

   - Ensure that the plan procedures are appropriate to conditions present following an earthquake as described above.
   - Ensure that all plausible earthquake scenarios have been considered.
   - Ensure that procedures are in place for operator action that is necessary to mitigate a seismic vulnerability.
   - Ensure that personnel training has been considered and implemented for all actions necessary to mitigate a seismic vulnerability.
   - Ensure that any emergency equipment or necessary controls will be accessible after a seismic event if they are needed to mitigate a seismic vulnerability.

3. **Review of Existing ERP.** The flow chart in Figure 6-1 describes the risk management implementation process. The final step in that process is an assessment of the facility ERP. It is recommended that a critical review of the ERP, including considerations specific to earthquake hazards as outlined above, be performed.

Table 6-1: Example Risk Classification and Acceptance Criteria

(Note: Numbers are shown for illustrative purposes only)

Risk	Category	Description of Acceptance Criteria
I	Very High	Mitigation via analysis, repair, replacement, or emergency plan procedures to achieve a minimum risk rank of III is recommended within 6 months. Recommended for components and systems with scores below 2.5.
II	High	Mitigation via analysis, repair, replacement,, or emergency plan procedures to achieve a minimum risk rank of III is recommended within 12 months. Recommended for components and systems with scores between 2.5 and 3.5.
III	Moderate	Recommended mitigation includes ensuring that the emergency plan includes procedures for responding to damage to the system or component. Recommended for components and systems with scores between 3.5 and 4.5.
IV	Low	No mitigation recommended. Recommended for components and systems with scores above 4.5.

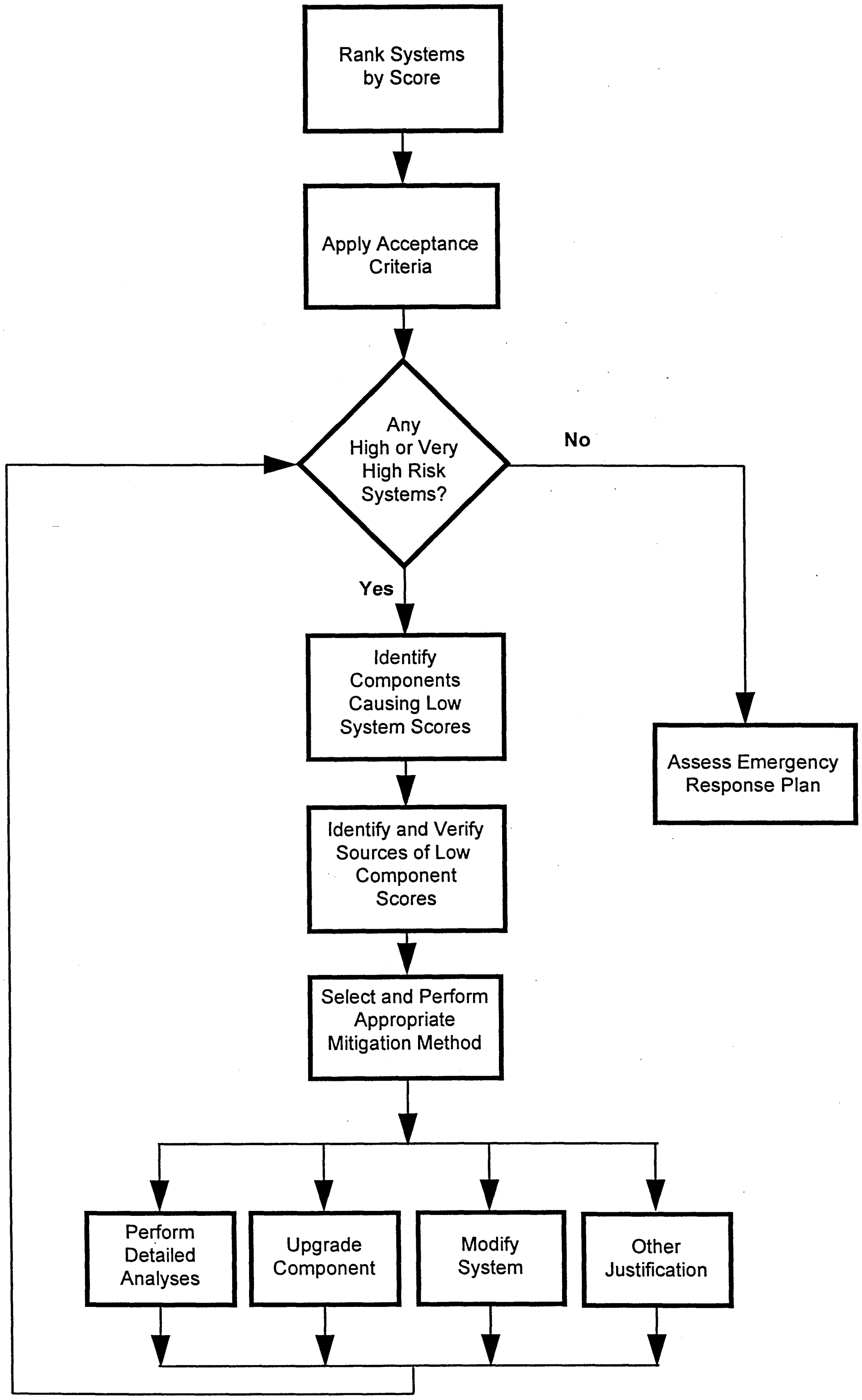


Figure 6-1: Risk Management Implementation

Appendix A

Checklists for Use in System Identification

Table A-1

FIRE RESPONSE CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: FIRE RESPONSE

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Detection And Alarm

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Detection					
A.1 Area/Spot Smoke Detectors	E	R	N	____	____
A.2 Line Smoke Detectors	E	R	N	____	____
A.3 HVAC/Plenum Smoke Detectors	E	R	N	____	____
A.4 Heat Detectors	E	R	N	____	____
A.5 Sprinkler Flow Sensors	E	R	N	____	____
A.6 Pull Stations	E	R	N	____	____
A.7 Other(define)	E	R	N	____	____
____	E	R	N	____	____
B. Alarms					
B.1 Bell/Siren Alarms	E	R	N	____	____
B.2 Speakers	E	R	N	____	____
B.3 Strobe Lights	E	R	N	____	____
B.4 Remote Alarm Monitors (specify)	E	R	N	____	____
____	E	R	N	____	____
B.5 Other (define)	E	R	N	____	____
____	E	R	N	____	____
C. Detection/Alarm Interface					
C.1 Computer System	E	R	N	____	____
C.2 Fire Communication Center	E	R	N	____	____
C.3 Alarm Panel(s)	E	R	N	____	____
C.4 Cabling/Conduit	E	R	N	____	____
C.5 Other (define)	E	R	N	____	____
____	E	R	N	____	____

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ____
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ____
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Fire Suppression

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Manual Suppression					
A.1 Hand Extinguishers	E	R	N	________	________
A.2 Hose Stations	E	R	N	________	________
A.3 Hose Station Water Supply (if different from Automatic System)	E	R	N	________	________
A.4 Other(define)	E	R	N	________	________
________	E	R	N	________	________
B. Automatic Suppression - Water					
B.1 City Water Supply	E	R	N	________	________
B.2 On-site Water Supply	E	R	N	________	________
B.3 Motor-Driven Fire Pump(s)	E	R	N	________	________
B.4 Diesel Driven Fire Pump(s)	E	R	N	________	________
B.4.a Diesel Start System	E	R	N	________	________
B.4.b Diesel Day Tank	E	R	N	________	________
B.4.c Diesel Piping/Valves	E	R	N	________	________
B.4.d Diesel Aux Fuel Supply	E	R	N	________	________
B.5 Fire Water Feed Main	E	R	N	________	________
B.6 Fire Water Cross Mains	E	R	N	________	________
B.7 Fire Water Branch Lines	E	R	N	________	________
B.8 Fire Water Risers	E	R	N	________	________
B.9 Sprinkler Heads	E	R	N	________	________
B.10 Deluge/Alarm Valves	E	R	N	________	________
B.11 Other (define)	E	R	N	________	________
________	E	R	N	________	________
C. Automatic Suppression - Gas					
C.1 Gas Storage (Halon/Other)	E	R	N	________	________
C.2 Connection to Detectors	E	R	N	________	________
C.3 Other (define)	E	R	N	________	________
________	E	R	N	________	________

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Air Duct Fire and Smoke Barriers

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Fire and Smoke Barriers			
A.1 Fire and Smoke Dampers	E R N	______	______
A.4 Other(define)	E R N	______	______
______	E R N	______	______

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Smoke Purge

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Detection			
A.1 Fire Control Center Panel	E R N		
A.2 Other(define)	E R N	______	______
______	E R N	______	______
B. Pressurization			
B.1 Fans	E R N	______	______
B.2 Actuation	E R N	______	______
B.3 Other (define)	E R N	______	______
______	E R N	______	______
C. Purge Pathway			
C.1 Break Window System	E R N	______	______
C.2 Other (define)	E R N	______	______
______	E R N	______	______

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-2

GAS SHUTOFF CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: GAS SHUTOFF

DEFINITION OF SYSTEM

____

____

____

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Manual Shutoff					
A.1 Manual Shutoff Valve	E	R	N	________	________
A.2 Other(define)	E	R	N	________	________
________________	E	R	N	________	________
B. Automatic Shutoff					
B.1 Fire Control Center Panel	E	R	N	________	________
B.2 Automatic Valve	E	R	N	________	________
B.3 Loss of Normal Building Power (if results in closure of valve)	E	R	N	________	________
				________	________
B.4 Cabling/Conduit	E	R	N	________	________
B.5 Other (define)	E	R	N	________	________
________________	E	R	N	________	________

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-3

ELEVATOR SAFETY CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: ELEVATOR SAFETY

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Detection/Control

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Detection					
A.1 Derailment Detectors	E	R	N	________	________
A.2 Ring and String Detectors	E	R	N	________	________
A.3 Loss of Normal Power	E	R	N	________	________
A.4 Other(define)	E	R	N	________	________
________________	E	R	N	________	________
B. Controls					
B.1 Elevator Controllers	E	R	N	________	________
B.2 Cables/Conduits	E	R	N	________	________
B.3 Other (define)	E	R	N	________	________
________________	E	R	N	________	________

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-4

BUILDING/EVACUATION EGRESS CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: BUILDING/EVACUATION EGRESS

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Alarm/Indication

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Alarm/Indication			
A.1 Annunciation	E R N	________	________
A.2 FCC Panel	E R N	________	________
A.3 Other(define)	E R N	________	________
________________	E R N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Available Routes

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Stairways			
A.1 Stairwell Emergency Lighting	E R N	________	________
A.2 Other(define)	E R N	________	________
________________	E R N	________	________
B. Elevator Operability			
B.1 Passenger Elevators	E R N	________	________
B.2 Freight Elevators	E R N	________	________
B.3 Other (define)	E R N	________	________
________________	E R N	________	________

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-5

LIGHTING/POWER CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: LIGHTING/POWER

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Lighting/Tenant Power

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Lighting/Tenant Power					
A.1 Normal Building Power	E	R	N	________	________
A.2 Temporary Lighting	E	R	N	________	________
A.3 Other(define)	E	R	N	________	________
________________	E	R	N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Normal Building Power

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Normal Building Power					
A.1 Off-site Power Supply	E	R	N	________	________
A.2 Transformers	E	R	N	________	________
A.3 Switchgear	E	R	N	________	________
A.4 Motor Control Centers	E	R	N	________	________
A.5 Distribution Panels	E	R	N	________	________
A.6 Substations	E	R	N		
A.7 Power Conditioners	E	R	N		
A.8 Motor Generators	E	R	N		
A.9 Conduit	E	R	N	________	________
A.10 Other(define)	E	R	N	________	________
________________	E	R	N	________	________

B. Emergency Power

B.1 Uninterruptible Power Supply	E	R	N	____	____
B.1.a UPS Inverters	E	R	N	____	____
B.1.b UPS Switchgear	E	R	N	____	____
B.1.c UPS Batteries	E	R	N	____	____
B.1.d UPS Rectifiers	E	R	N	____	____
B.1.e Other (define)	E	R	N	____	____
____	E	R	N	____	____
B.2 Backup Generators (typ. Diesel)	E	R	N	____	____
B.2.a Generator	E	R	N	____	____
B.2.b Starter	E	R	N	____	____
B.2.c Control Equipment	E	R	N	____	____
B.2.d Fuel Tank	E	R	N	____	____
B.2.e Fuel Pump	E	R	N	____	____
B.2.f Day Tank	E	R	N	____	____
B.2.g Fuel Piping	E	R	N	____	____
B.2.h Auto Safety Fuel Valve	E	R	N	____	____
B.2.i Other (define)	E	R	N	____	____
____	E	R	N	____	____
B.3 Portable Generators	E	R	N	____	____
B.4 Other (define)	E	R	N	____	____
____	E	R	N	____	____

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ____
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ____
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-6

WATER SUPPLY/WASTE REMOVAL CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: WATER SUPPLY/WASTE REMOVAL

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Water Supply

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Water Supply					
A.1 Normal Water Supply	E	R	N	________	________
A.2 Backup Water Supply	E	R	N	________	________
A.3 Temporary Water Supply	E	R	N	________	________
A.4 Other(define)	E	R	N	________	________
________________	E	R	N	________	________
B. Water Distribution					
B.1 Domestic Water Pumps	E	R	N	________	________
B.2 Fresh Water Piping	E	R	N	________	________
B.3 Plumbing Fixtures (sinks, etc.)	E	R	N	________	________
B.4 Other(define)	E	R	N	________	________
________________	E	R	N	________	________

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Sewage Removal

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Sewage Removal					
A.1 Waste Water Piping	E	R	N	________	________
A.2 Sewer Services	E	R	N	________	________
A.3 Other(define)	E	R	N	________	________
________________	E	R	N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-7

STORM DRAINAGE CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: STORM DRAINAGE

DEFINITION OF SYSTEM

____

____

____

	Criticality (circle one) E-essential, R-redundant, N-non-essential	**Redundant Component** List redundant item number	**Support System Required** List function (i.e., power, cooling water, etc.)
A. Storm Drains			
A.1 Storm Drain Lines	E R N	________	________
A.2 Other(define)	E R N	________	________
________________	E R N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-8

NORMAL PERSONNEL TRANSPORT CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: NORMAL PERSONNEL TRANSPORT

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Elevators

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Elevators					
A.1 Passenger Elevators	E	R	N	________	________
A.2 Freight Elevators	E	R	N	________	________
A.3 Other (define)	E	R	N	________	________
________________	E	R	N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-9

BUILDING HVAC CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: BUILDING HVAC

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Heating

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Heating Equipment					
A.1 Gas Lines	E	R	N	________	________
A.2 Boilers	E	R	N	________	________
A.3 Heat Exchangers	E	R	N	________	________
A.4 Other (define)	E	R	N	________	________
________________	E	R	N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Ventilation

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Ventilation Equipment					
A.1 Fans	E	R	N	________	________
A.2 Ducting	E	R	N	________	________
A.3 Control Dampers	E	R	N	________	________
A.4 Other (define)	E	R	N	________	________
________________	E	R	N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Air Conditioning

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Air Conditioning Equipment					
A.1 Cooling Towers	E	R	N	________	________
A.2 Chillers	E	R	N	________	________
A.3 Chilled Water Distribution	E	R	N	________	________
A.4 Special Air Conditioning Units	E	R	N	________	________
A.5 Other (define)	E	R	N	________	________
________	E	R	N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: HVAC Control

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Pneumatic System					
A.1 Air Compressors	E	R	N	________	________
A.2 Air Receivers	E	R	N	________	________
A.3 Header Piping	E	R	N	________	________
A.4 Tubing	E	R	N	________	________
A.5 Control Panel	E	R	N	________	________
A.6 Other (define)	E	R	N	________	________
________	E	R	N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-10

COMMUNICATIONS CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: COMMUNICATIONS

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Telephone/Communications

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Telephone Voice Communications			
A.1 Telephone/Direct Lines	E R N	________	________
A.2 PBX System	E R N	________	________
A.3 Cellular Phones	E R N	________	________
A.4 Other (define)	E R N	________	________
____________	E R N	________	________
B. Alternate Voice Communications			
B.1 CB's	E R N	________	________
B.2 Ham Radios	E R N	________	________
B.3 Walkie Talkies	E R N	________	________
B.4 Other (define)	E R N	________	________
____________	E R N	________	________

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Data Telecommunications

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Telecommunications Equipment					
A.1 Cable Entrance Facility	E	R	N		
A.2 Cable/Cable Trays	E	R	N		
A.3 Switching Equipment	E	R	N		
A.4 Billing Tape Drive	E	R	N		
A.5 Main Distribution Frame	E	R	N		
A.6 Multiplexing Equipment	E	R	N		
A.7 Demultiplexing Equipment	E	R	N		
A.8 Equipment Monitors	E	R	N		
A.9 Microwave System	E	R	N		
A.9.a Antenna	E	R	N		
A.9.b Antenna Tower	E	R	N		
A.9.c Signal Equipment	E	R	N		
A.10 Other (define)	E	R	N		
______	E	R	N		

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-11

DATA PROCESSING CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: DATA PROCESSING

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: Data Processing Equipment

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Data Processing Components					
A.1 Mass Storage Facilities	E	R	N	______	______
A.2 Storage Devices	E	R	N	______	______
A.3 Communication Control Equip.	E	R	N	______	______
A.4 Communications Cable	E	R	N	______	______
A.5 Printers	E	R	N	______	______
A.6 Document Handling Equipment	E	R	N	______	______
A.7 Other (define)	E	R	N	______	______
______	E	R	N	______	______

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Computer Equipment

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Computers					
A.1 Mainframe Computers	E	R	N	______	______
A.2 Other Computers	E	R	N	______	______
A.3 Other (define)	E	R	N	______	______
______	E	R	N	______	______

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-12

REFRIGERATION CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: REFRIGERATION

DEFINITION OF SYSTEM

____

____

____

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Refrigeration			
A.1 Critical Supplies	E R N	________	________
A.2 Other(define)	E R N	________	________
________	E R N	________	________

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-13

GAS SUPPLY CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: GAS SUPPLY

DEFINITION OF SYSTEM

____

____

____

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Normal Gas Supply					
A.1 Gas Supply______	E	R	N	______	______
A.1.a Tank	E	R	N	______	______
A.1.b Cooling Coils	E	R	N	______	______
A.1.c Supply Line	E	R	N	______	______
A.2 Gas Supply______	E	R	N	______	______
A.2.a Tank	E	R	N	______	______
A.2.b Cooling Coils	E	R	N	______	______
A.2.c Supply Line	E	R	N	______	______
A.3 Gas Supply______	E	R	N	______	______
A.3.a Tank	E	R	N	______	______
A.3.b Cooling Coils	E	R	N	______	______
A.3.c Supply Line	E	R	N	______	______
A.4 Other(define)	E	R	N	______	______
______	E	R	N	______	______
B. Backup Gas Supply					
B.1 Backup Gas Unit	E	R	N	______	______
B.2 Other(define)	E	R	N	______	______
______	E	R	N	______	______

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

____
(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

____
(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-14

STRUCTURAL CONCERNS CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: STRUCTURAL CONCERNS

DEFINITION OF SYSTEM

____

____

____

	Criticality (circle one) E-essential, R-redundant, N-non-essential	Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Raised Access Floor			
A.1 Structural Integrity	E R N	________	________
A.2 Other(define)	E R N	________	________
________	E R N	________	________
B. Other ________		________	________
B.1 Other(define)	E R N	________	________
________	E R N	________	________

C. General Items

C.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

C.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table A-15

CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: ______________________________

DEFINITION OF SYSTEM

____

____

____

SUB-SYSTEM: ______________________________

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. __________					
A.1	E	R	N	________	________
A.2	E	R	N	________	________
A.3	E	R	N	________	________
A.4	E	R	N	________	________
A.5	E	R	N	________	________
A.6	E	R	N	________	________
B. __________					
B.1	E	R	N	________	________
B.2	E	R	N	________	________
B.3	E	R	N	________	________
B.4	E	R	N	________	________
B.5	E	R	N	________	________
B.6	E	R	N	________	________
C. __________					
C.1	E	R	N	________	________
C.2	E	R	N	________	________
C.3	E	R	N	________	________
C.4	E	R	N	________	________
C.5	E	R	N	________	________
C.6	E	R	N	________	________

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Appendix B

Detailed Component Worksheets

Index of Components Included in Rapid Visual Screening Score Sheets
(Sorted Alphabetically by Score Sheet Identifier)

Component	Score Sheet	Classification
Ductwork	DS-01	Distribution Systems
Piping (buried)	DS-01	Distribution Systems
Piping (above ground)	DS-02	Distribution Systems
Cable	DS-03	Distribution Systems
Cable Tray	DS-03	Distribution Systems
Conduit	DS-03	Distribution Systems
Motor Control Center	EL-01	Electrical Equipment
Switchgear	EL-02	Electrical Equipment
Transformer	EL-03	Electrical Equipment
Control Panel	EL-04	Electrical Equipment
Distribution Panel	EL-05	Electrical Equipment
Battery Rack	EL-06	Electrical Equipment
Battery Charger	EL-07	Electrical Equipment
Generator	EL-08	Electrical Equipment
Alarm (fire pull station)	FP-01	Fire Protection Equipment
Alarm (smoke, fire, heat)	FP-01	Fire Protection Equipment
Detectors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Monitors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Sensors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Dampers (smoke, fire)	FP-02	Fire Protection Equipment
Fire Extinguisher	FP-02	Fire Protection Equipment
Fire hose station	FP-02	Fire Protection Equipment
Valve (fuel shutoff)	FP-02	Fire Protection Equipment
Piping (fire protection)	FP-03	Fire Protection Equipment
Sprinkler Head	FP-03	Fire Protection Equipment
Fan	HV-01	HVAC Equipment
Air Handler	HV-02	HVAC Equipment
Chiller	HV-03	HVAC Equipment
Lighting (in suspended ceiling)	MB-01	Miscellaneous Building Components
Raised Access Floor	MB-01	Miscellaneous Building Components
Suspended Ceiling	MB-01	Miscellaneous Building Components
Elevator	MB-02	Miscellaneous Building Components
Elevator (derailment detector)	MB-02	Miscellaneous Building Components
Communications Control Equip.	MC-01	Miscellaneous Computer Equipment
Computer (mainframe)	MC-01	Miscellaneous Computer Equipment
Computer (micro, pc)	MC-01	Miscellaneous Computer Equipment
Computer (mini)	MC-01	Miscellaneous Computer Equipment

Index of Components Included in Rapid Visual Screening Score Sheets
(Sorted Alphabetically by Score Sheet Identifier) (Cont.)

Component	Score Sheet	Classification
Computer (peripherals)	MC-01	Miscellaneous Computer Equipment
Document Handling Equipment	MC-02	Miscellaneous Computer Equipment
Media Rack	MC-02	Miscellaneous Computer Equipment
Medical Equipment (lab)	MD-01	Medical Equipment
Medical Equipment (unit)	MD-01	Medical Equipment
Refrigerators (blood bank)	MD-01	Medical Equipment
Generator (portable)	ME-01	Miscellaneous Electrical Equipment
Power Transfer Equipment	ME-01	Miscellaneous Electrical Equipment
Lighting (emergency stairway)	ME-02	Miscellaneous Electrical Equipment
Lighting (temporary)	ME-02	Miscellaneous Electrical Equipment
Pump	MN-01	Mechanical Equipment
Valve	MN-02	Mechanical Equipment
Compressor	MN-03	Mechanical Equipment
Cooling Tower	MN-04	Mechanical Equipment
Boiler	MN-05	Mechanical Equipment
Electrical Power (off-site)	OS-01	Off-Site Systems
Natural Gas (off-site)	OS-01	Off-Site Systems
Water, domestic (off-site)	OS-01	Off-Site Systems
Water, fire (off-site)	OS-01	Off-Site Systems
Cable Entrance Facility	TC-01	Telecommunications Equipment
Rack Mounted Components	TC-01	Telecommunications Equipment
Communications (microwave)	TC-02	Telecommunications Equipment
Communications (radio)	TC-02	Telecommunications Equipment
Communications (telephone)	TC-02	Telecommunications Equipment
Tank (on legs)	TK-01	Tanks
Heat Exchanger	TK-02	Tanks
Tank (horizontal)	TK-02	Tanks
Tank (vertical, anchored)	TK-03	Tanks
Drum	TK-04	Tanks
Tank (vertical, unanchored)	TK-05	Tanks

Rapid Visual Screening Score Sheet | DS-01

Above Ground Piping

ID Number ______________________

Comments ______________________

____

____

____

____

____

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**5.7**	**5.2**	**4.8**	**4.3**	**3.9**
	1. No lateral support - possible falling of pipe.	1.9	1.9	1.9	1.9	1.9
P	2. Questionable vertical support system for pipe.	2.4	2.4	2.4	2.4	2.4
M	3. Short stiff branches attached to long flexible headers.	1.5	1.5	1.5	1.5	1.5
F	4. Inadequate flexibility where piping crosses seismic gaps.	1.9	1.9	1.9	1.9	1.9
	5. Piping may impact rigid structural elements.	1.2	1.2	1.2	1.2	1.2
	6. Other______________________					
Final Score = Basic Score - **largest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | DS-01

Performance Modification Factors (PMFs)

1 If the pipe has no lateral supports, such as U-bolts, and no lateral stops, and could slide off of the support during an earthquake, select PMF 1. This is usually for relatively long straight runs.

2 Several support conditions represent a falling hazard for piping in an earthquake. Examples include use of powder driven fasteners for anchorage of the supports, C-clamps that an loosen and lose their friction connection, and brittle piping connections such as bell and spigot joints that can detach due to shaking (they should be supported on each side of the connection). If these or other situations exist that could lead to a pipe falling off its support during an earthquake, select PMF 2.

3 Rigid branch lines on flexible headers can attract significant load during a seismic event. This can lead to a damage and leakage at the branch / header interface. If this condition exists for the run of pipe, select PMF 3.

4 Pipe must have flexibility to accomodate differential motions at its anchor points. Differential motion can be encountered where pipe spans a seismic gap, a building crossing, etc. If the pipe is not able to withstand significant differential displacement of its supports, select PMF 4.

5 Certain pipe materials are brittle and can be damaged by impact with rigid structural elements. If the pipe is made of fiberglass, fiber reinforced plastic, PVC, cast iron, or other brittle material and could impact a rigid structural element, select PMF 5.

6 For other conditions that the reviewer believes could inhibit function following an earthquake, (e.g., a history of problems with this piping system, obvious external corrosion at flanges, etc.) assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet — DS-02

Buried Piping

ID Number ______________________

Comments ______________________

____

____

____

____

____

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Ductile Iron Piping

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**4.8**	**4.3**	**4**	**3.5**	**3.2**
PMF	1a. Cast Iron Piping	1	1	1	1	1
PMF	1b. PVC Piping	1	1	1	1	1
PMF	1c. Reinforced Concrete or Asbestos Cement Piping	1.2	1.2	1.2	1.2	1.2
PMF	2. Poor Soil / Differential Settlement	1.2	1.3	1.3	1.4	1.4
PMF	3. Other ______________________					
Final Score = Basic Score - **largest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs)

1 All PMFs for this category are related to the material of construction. If the pipe is constructed of cast iron, PVC, FRP, or Asbestos Cement, select the appropriate PMF.

2 If conditions exist where differential soil settlement could occur (e.g., liquefiable soils) select this PMF.

3 For other conditions that the reviewer believes could inhibit function following an earthquake, (e.g., a history of problems with this piping system) assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet — DS-03

Distribution Systems

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ____________________

Comments ____________________

Ductwork

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.3**	**4.8**	**4.4**	**3.9**	**3.5**
P	1. Ducts can slide off supports and fall.	1.7	1.7	1.7	1.7	1.7
M	2. Inadequate flexibility where ducting crosses seismic gaps, between buildings, between equipment, etc.	2.0	2.0	2.0	2.0	2.0
F	3. Obvious heavy corrosion on duct.	2.0	2.0	2.0	2.0	2.0
	4. Duct supported by suspended ceiling.	2.4	2.4	2.4	2.4	2.3
	5. Other____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Conduit, cable trays, and cable

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**
P	1. Cable trays can slide off supports and fall.	3.2	3.8	4.1	4.7	5.0
M	2. Very heavily loaded cable trays.	2.8	3.4	3.7	4.3	4.6
F	3. Other____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Page 1 of 2

Performance Modification Factors (PMFs) - Ducts

1 If the duct has no lateral supports, (typically clips), and is on a cantilevered support (nothing will stop it from sliding off) select PMF 1. This is primarily an issue when the duct can realistically fall, such as when it is cantilevered at one end, such as a supply or return duct.

2 Ducting must have flexibility to accomodate differential motions at its anchor points. Differential motion can be encountered where a duct spans a seismic gap, a building crossing, etc. Also, ducts with flexible joints and bellows, such as near rod-hung fans, should be supported on each side of the duct. If the duct is not able to withstand significant differential displacement of its supports, select PMF 2.

3 If the duct is heavily corroded, such that the reviewer questions its structural integrity, select PMF 3.

4 If the duct runs within a suspended ceiling and is not supported independently, select PMF 4.

5 For other conditions that the reviewer believes could inhibit function following an earthquake, (e.g., history of problems with the duct) assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Performance Modification Factors (PMFs) - Cable Trays and Others

1 If the cable tray or conduit has no lateral supports, such as U-bolts for a conduit or clips for a cable tray, and no lateral stops, and could slide off of the support during an earthquake, select PMF 1. This is usually for relatively long straight runs.

2 If the cable tray is so heavily loaded that it leads to questions regarding the structural capacity of the support system, select PMF 2. This would usually require cables to be loaded several inches above the side of the tray.

3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

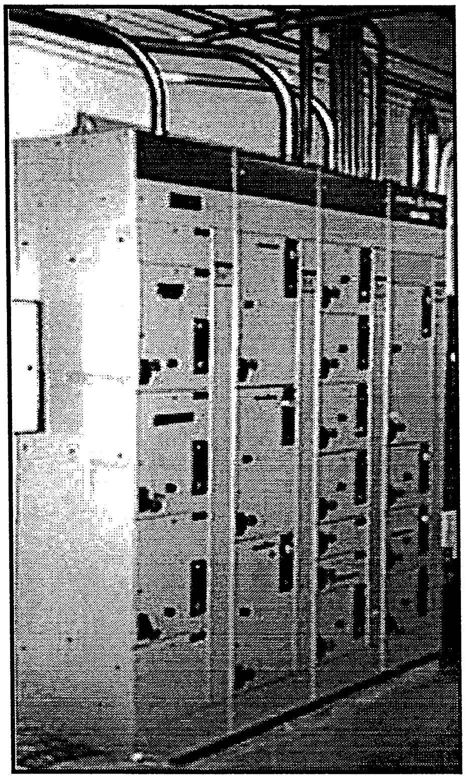
Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | EL-01

Motor Control Centers

ID Number ____________________

Comments ____________________



Earthquake Load Level (circle one letter)

ZONE	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Motor Control Centers

(circle a Basic Score and all PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.1**	**4.6**	**4.2**	**3.7**	**3.3**
PMF	1. No anchorage	1.5	1.5	1.5	1.5	1.5
PMF	2. "Poor" anchorage	1.3	1.3	1.3	1.3	1.3
PMF	3. Suspect load path	0.7	0.7	0.7	0.7	0.7
PMF	4. Pounding or impact concerns	0.9	0.9	0.9	0.9	0.9
PMF	5. Interaction concerns	0.9	0.9	0.9	0.9	0.9
PMF	6. Other ______					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

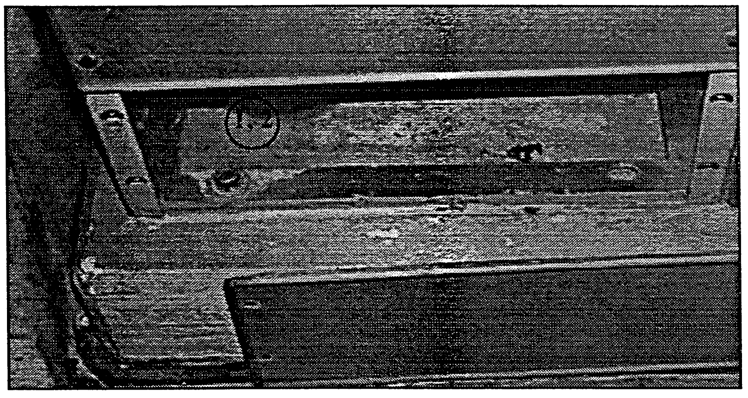
1, 2 As shown in the photo below, the anchorage of the MCC base to the floor or pad is sometimes difficult to see since it is typically behind the outer face of the unit. If you have reason to believe that there is no anchorage, select PMF 1. If the anchorage appears small compared to the size of the unit or appears to be damaged, select PMF 2. Top or side bracing to a wall, or rigid restraints from multiple conduits may effectively act as anchorage.

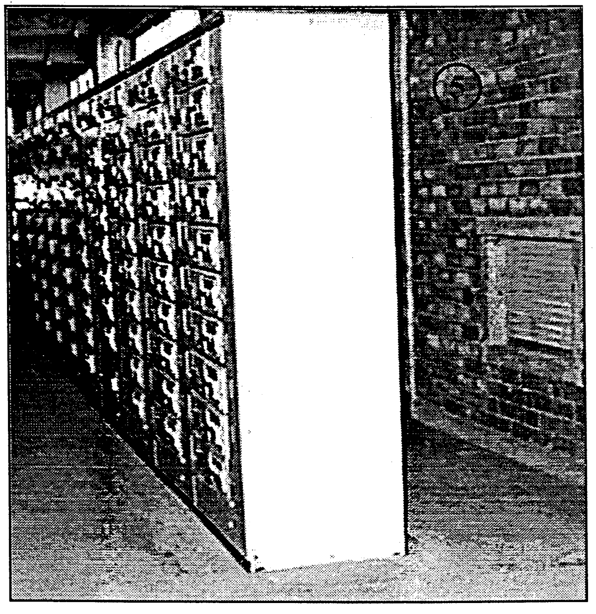
3 There should be a definite and continuous load path from the internal components of the MCC to the anchorage at the base. The photo below shows a definite weakness in the load path. Another example is large, unreinforced cut-outs in the sheet metal enclosure which could weaken its structural integrity. If these conditions exist, select PMF 3.

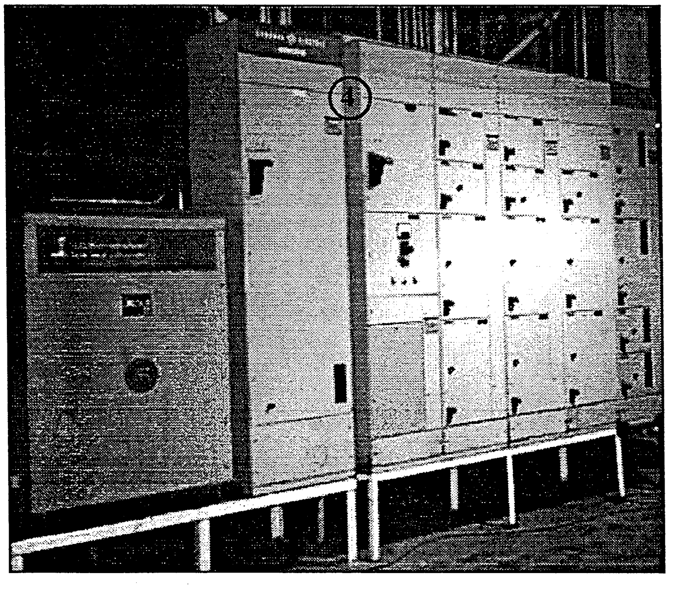
4 If adjacent cabinets are not attached and are within about 1/2" of each other, there is a potential for pounding between the two. If so, select PMF 4

5 If large items, such as non-structural walls, could fall and impact the MCC, PMF 5 should be selected.

6 For other conditions that the reviewer believes could inhibit MCC function following an earthquake, (e.g., a history of problems with this piece of equipment) assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Rapid Visual Screening Score Sheet	EL-02

Switchgear

ID Number ________________________________

Comments ________________________________

____

____

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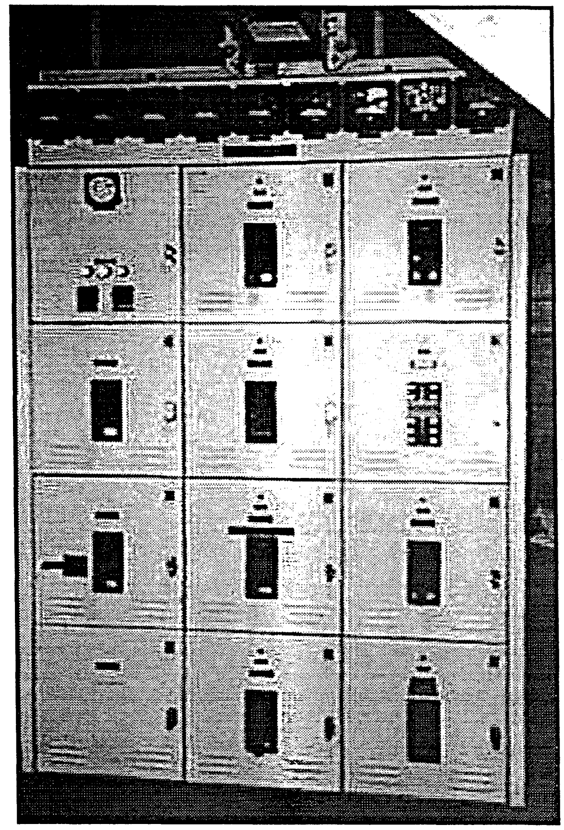


Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

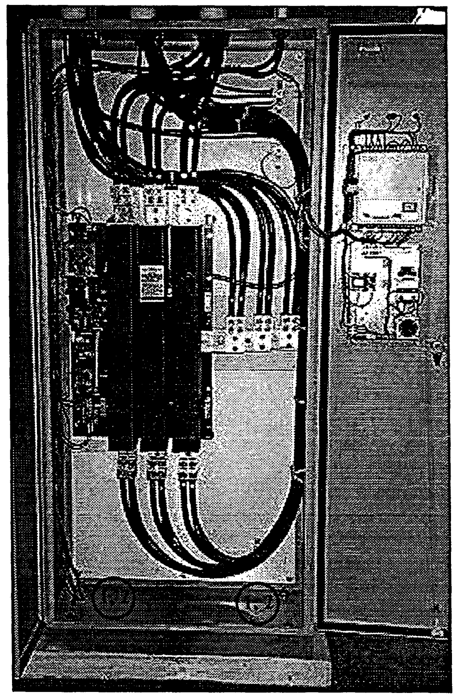
Scores and Modifiers - Switchgear

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**4.8**	**4.3**	**3.9**	**3.4**	**3.0**
	1. No anchorage	1.0	1.0	1.0	1.0	1.0
P	2. "Poor" anchorage	0.8	0.8	0.8	0.8	0.8
M	3. Suspect load path	0.6	0.6	0.6	0.6	0.6
F	4. Pounding or impact concerns	0.5	0.5	0.5	0.5	0.5
	5. Interaction concerns	0.6	0.6	0.6	0.6	0.6
	6. Other ______________					
Final Score = Basic Score - **highest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)



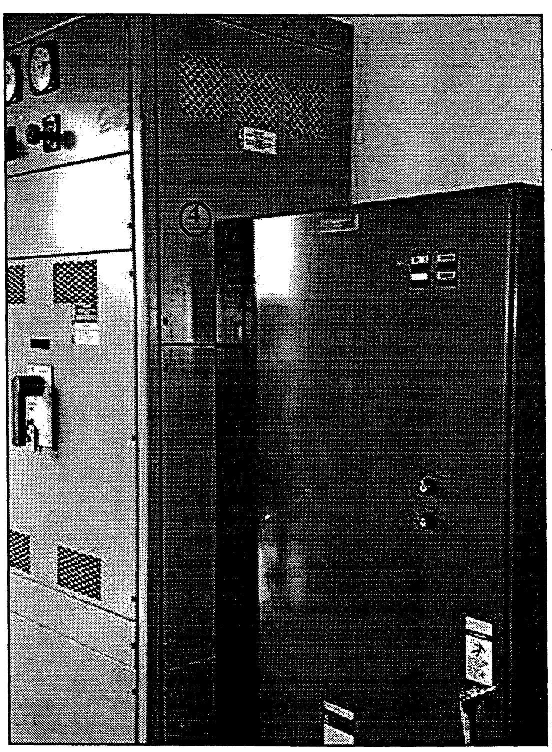
1, 2 As shown in the photo to the right, switchgear anchorage is sometimes difficult to see since it is typically behind the outer face of the unit. If you have reason to believe that there is no anchorage, select PMF 1. If the anchorage appears small compared to the size of the unit or the anchorage appears to be damaged, select PMF 2.

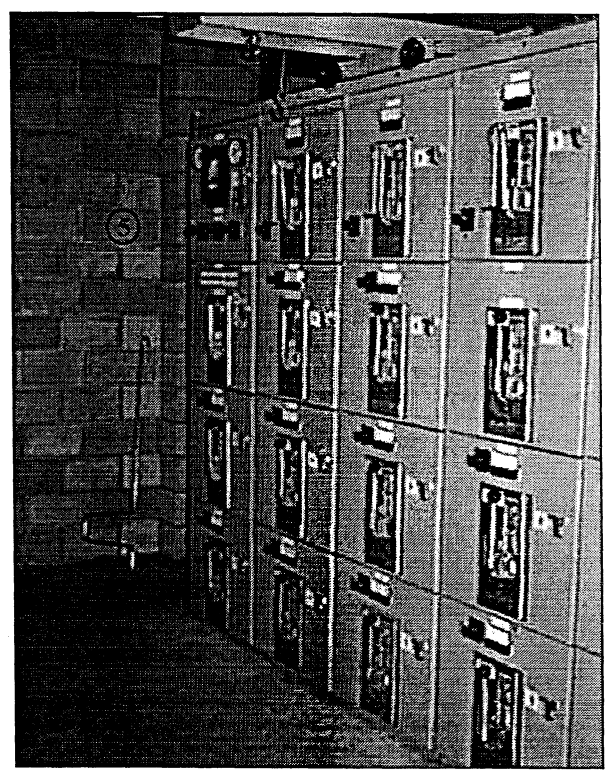
3 There should be a definite and continuous load path from the internal components of the switchgear to the anchorage at the base. Large, unreinforced cut-outs in the sheet metal enclosure which could weaken its structural integrity are an example of a load path concern. If there are concerns regarding the integrity of the load path, select PMF 3.

4 If adjacent cabinets are not attached and are within about 1/2" of each other (as shown below), there is a potential for pounding between the two. If so, select PMF 4.

5 If large items, such as non-structural walls, could fall and impact the switchgear, PMF 5 should be selected.

6 For other conditions that the reviewer believes could inhibit switchgear function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





Rapid Visual Screening Score Sheet — EL-03

Transformers

ID Number ______________________________

Comments ______________________________

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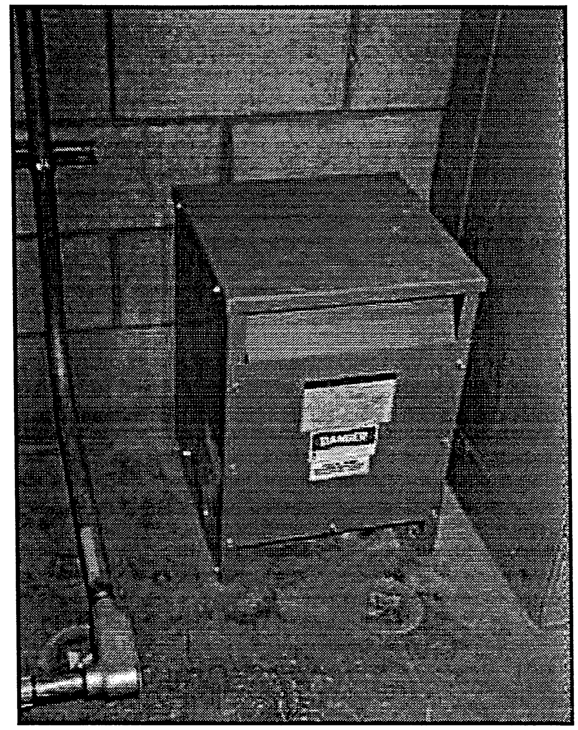


Earthquake Load Level (circle one letter)

ZONE	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Transformers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.2**	**4.7**	**4.3**	**3.8**	**3.4**
PMF	1. No anchorage	1.7	1.7	1.7	1.7	1.7
PMF	2. "Poor" anchorage	1.4	1.4	1.4	1.4	1.4
PMF	3. Pounding/impact concerns	0.6	0.6	0.6	0.6	0.6
PMF	4. Poor load path	0.9	0.9	0.9	0.9	0.9
PMF	5. Interaction concerns	1.0	1.0	1.0	1.0	1.0
PMF	6. Coils not firmly restrained	1.2	1.2	1.2	1.2	1.2
PMF	7. Other ______________					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

1, 2 Select PMF 1 if there is no anchorage as shown in the photo below. If the anchorage appears small compared to the size of the transformer, or is damaged, select PMF 2.

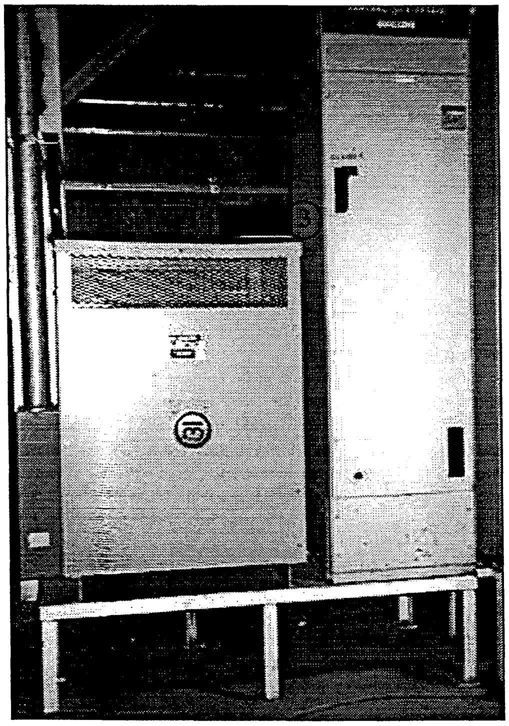
3 If adjacent cabinets are not attached and are within about 1/2" of each other (see photo), there is a potential for pounding between the two. If so, select PMF 3.

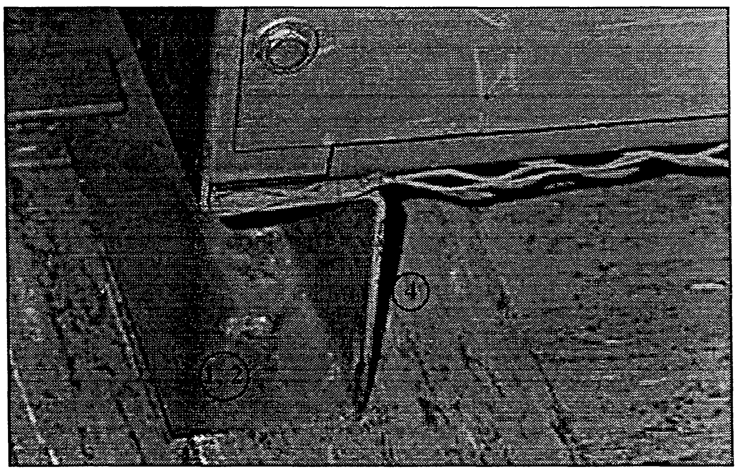
4 The typical channel supports for transformers shown in the photo below have some weakness from side-to-side loading. If thin gage sheet metal is used at the base, select PMF 4.

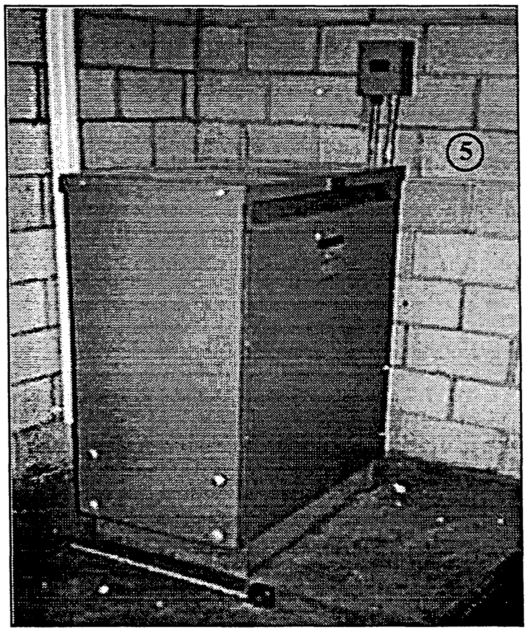
5 If large items, such as non-structural walls, could fall and impact the transformer, PMF 5 should be selected.

6 Internal coils are sometimes only temporarily anchored for transportation, and these bolts may be removed. If the coils are unrestrained, or are flexible and unbraced and of such a size that the coils could displace and short out, this PMF should be selected.

7 For other conditions not mentioned above, that the reviewer believes could inhibit transformer function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





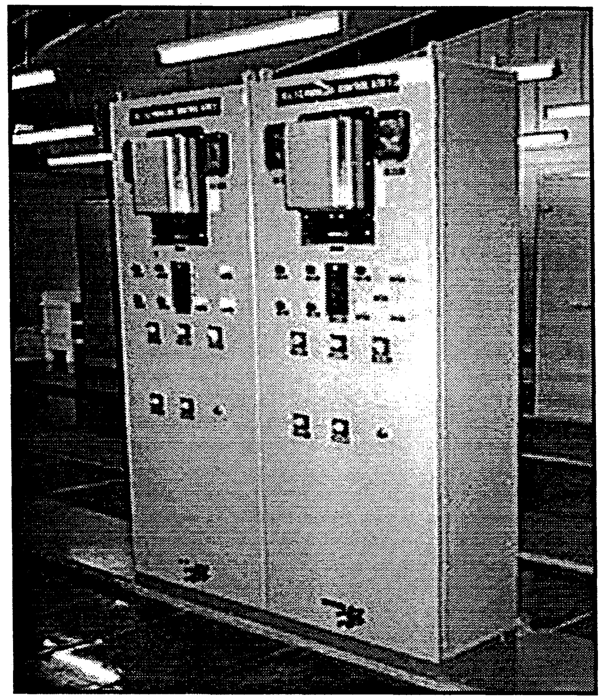


Rapid Visual Screening Score Sheet | EL-04

Control and Instrumentation Panels

ID Number ______________________

Comments ______________________



Earthquake Load Level (circle one letter)

ZONE	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Control and Instrumentation Panels

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.8**	**5.3**	**4.9**	**4.4**	**4.0**
PMF	1. No anchorage	2.2	2.2	2.2	2.2	2.2
PMF	2. "Poor" anchorage	2.0	2.0	2.0	2.0	2.0
PMF	3. Suspect load path	2.2	2.2	2.2	2.2	2.2
PMF	4. Pounding or impact concerns	1.2	1.2	1.2	1.2	1.2
PMF	5. Inflexible attachments	2.2	2.2	2.2	2.2	2.2
PMF	6. Interaction concerns	2.5	2.5	2.5	2.5	2.5
PMF	7. Other ______					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

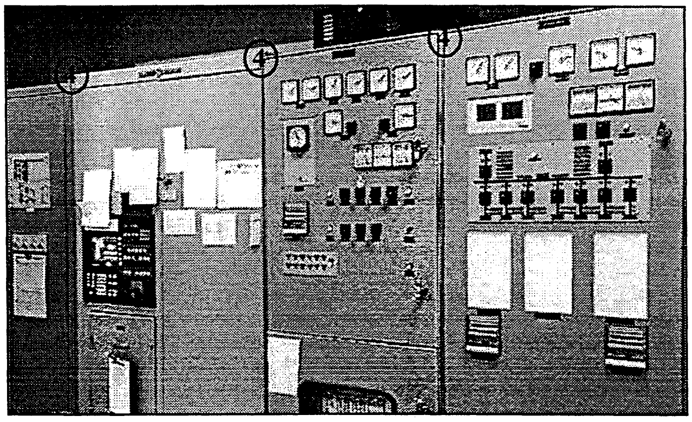
1, 2 As shown in the photo below, control panel anchorage is sometimes difficult to see since it is typically behind the outer face of the unit. If you have reason to believe that there is no anchorage, select PMF 1. If the anchorage appears small compared to the size of the unit or the anchorage appears to be damaged, select PMF 2.

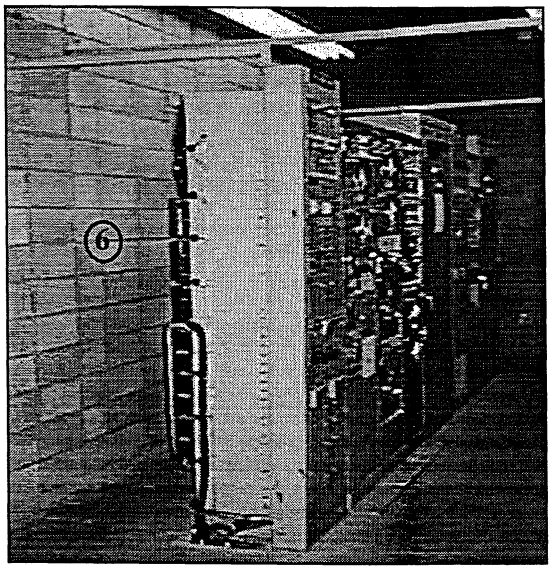
3 There should be a definite and continuous load path from the internal components of the panel to the anchorage at the base. Cut-outs in the sheet metal enclosure which could weaken its structural integrity are an example of a load path concern. If there are concerns regarding the integrity of the load path, select PMF 3.

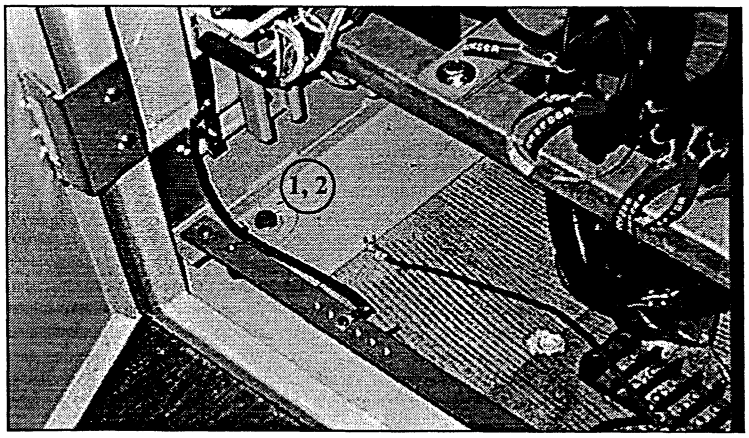
4 If adjacent cabinets are not attached and are within about 1/2" of each other (as shown below), there is a potential for pounding between the two. This is an issue for control cabinets, as they tend to contain shaking or impact sensitive devices, such as relays. If so, select PMF 4.

5 If large items, such as non-structural walls, could fall and impact the panel, PMF 5 should be selected.

6 For other conditions that the reviewer believes could inhibit panel function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Rapid Visual Screening Score Sheet | EL-05

Distribution Panels

ID Number ______________________________

Comments ______________________________

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Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Distribution Panels

(circle a Basic Score and <u>all</u> PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6.2**	**5.7**	**5.3**	**4.8**	**4.4**
PMF	1. No anchorage	2.4	2.4	2.4	2.4	2.4
	2. "Poor" anchorage	2.2	2.2	2.2	2.2	2.2
	3. Pounding or impact concerns	1.5	1.5	1.5	1.5	1.5
	4. Interaction concerns	1.5	1.5	1.5	1.5	1.5
	5. Other ____________					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

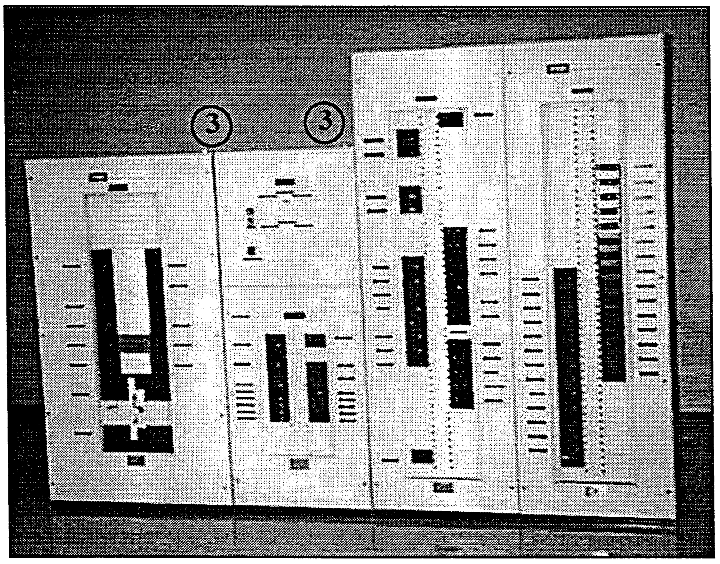
Performance Modification Factors (PMFs)

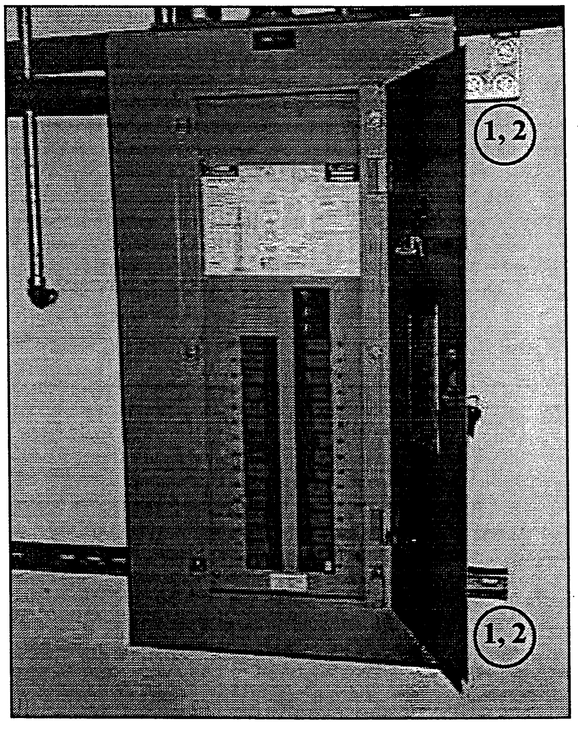
1, 2 Select PMF 1 if there is no anchorage. If the anchorage appears small compared to the size of the panel, or is damaged, select PMF 2.

3 If adjacent cabinets are not attached and are within 1/2" of each other, there is a potential for pounding between the two. If so, select PMF 3.

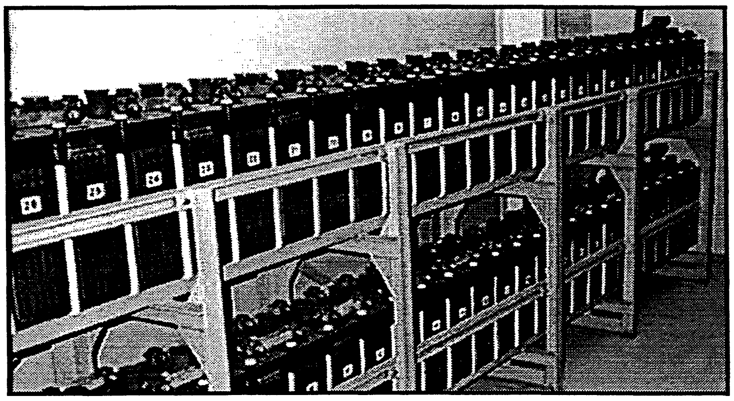
4 If large items, such as non-structural walls, could fall and impact the panel, PMF 4 should be selected.

5 For other conditions that the reviewer believes could inhibit distribution panel function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





Batteries and Racks



ID Number ______________________

Comments ______________________

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Earthquake Load Level (circle one letter)

ZONE	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Batteries and Racks

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6.0**	**5.5**	**5.1**	**4.6**	**4.2**
	1. No anchorage	2.2	2.2	2.2	2.2	2.2
	2. "Poor" anchorage	2.0	2.0	2.0	2.0	2.0
P	3. No battery spacers	2.2	2.2	2.2	2.2	2.2
M	4. No longitudinal cross-bracing	2.0	2.0	2.0	2.0	2.0
F	5. No battery restraints	2.4	2.4	2.4	2.4	2.4
	6. Interaction concerns	2.4	2.4	2.4	2.4	2.4
	7. Other ____________					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

1, 2 If there are no anchor bolts at the base of the frame, select PMF 1. If the anchors appear to be undersized, if there are not anchors for every frame of the rack, or if the anchorage appears to be damaged select PMF 2.

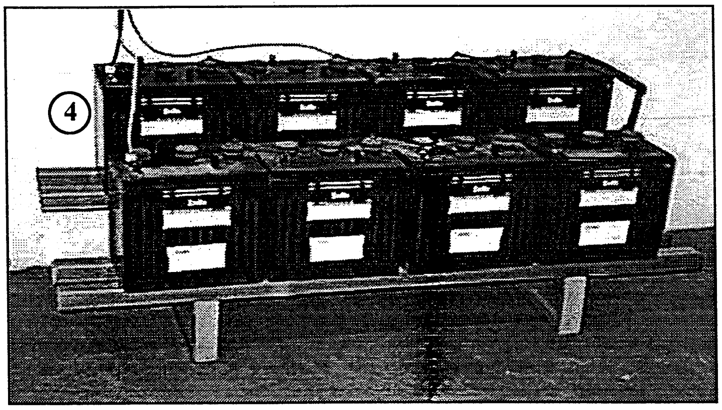
3 Look for stiff spacers, such as Styrofoam, between the batteries that fit snugly to prevent battery pounding. If there are none, select PMF 3.

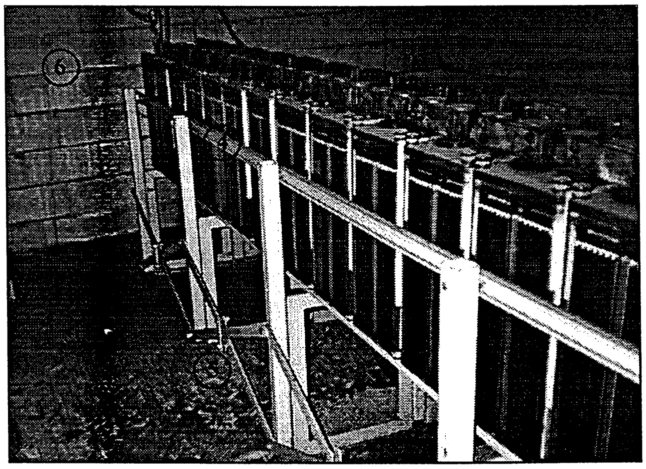
4 The rack should provide restraints to assure that the batteries will not fall off. The top photo shows a rack with no restraints, while the photo to the left shows a rack with restraints. Select PMF 4 if adequate restraint is not provided.

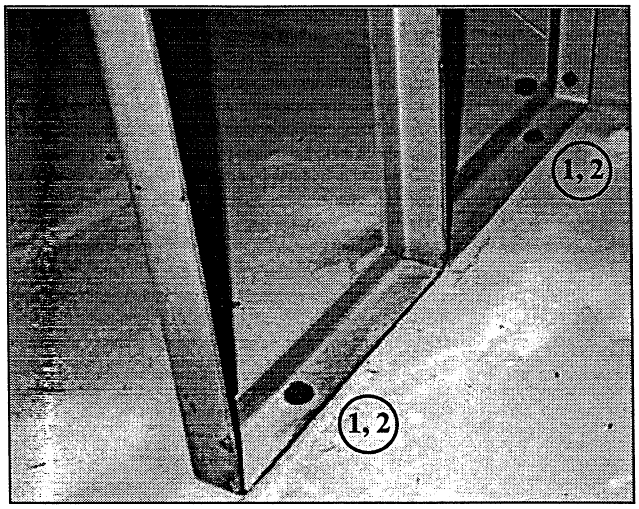
5 Racks with long rows of batteries need to be sufficiently stiff or braced longitudinally as shown in the photo to the left. Select PMF 5 if no cross-bracing is present.

6 If large items such as non-structural walls could fall and impact the battery racks, select PMF 6.

7 For other conditions that the reviewer believes could inhibit battery function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





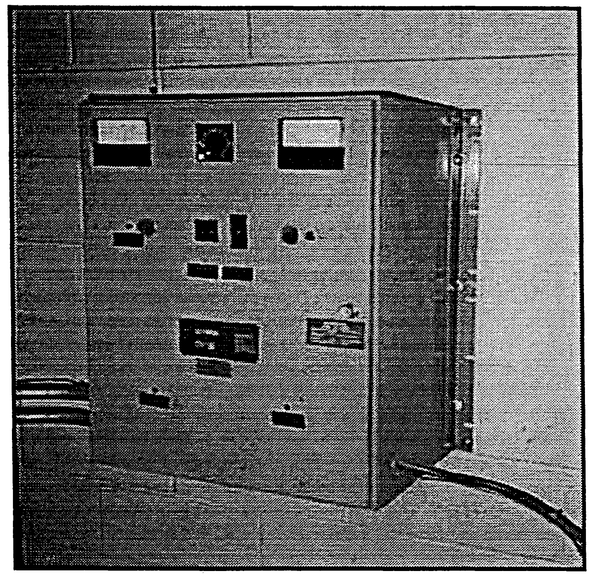


Rapid Visual Screening Score Sheet — EL-07

Battery Chargers

ID Number ______________________

Comments ______________________



Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Battery Chargers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**5.6**	**5.1**	**4.7**	**4.2**	**3.8**
	1. No anchorage	1.8	1.8	1.8	1.8	1.8
	2. "Poor" anchorage	1.6	1.6	1.6	1.6	1.6
P	3. Load path concerns	0.8	0.8	0.8	0.8	0.8
M	4. Pounding or impact concerns	0.8	0.8	0.8	0.8	0.8
F	5. Interaction concerns	1.4	1.4	1.4	1.4	1.4
	6. Other ______					
Final Score = Basic Score - **highest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

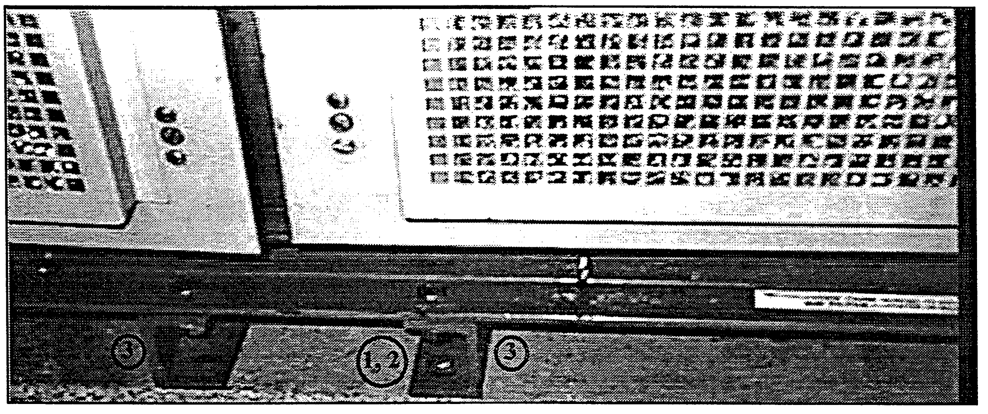
1, 2 Select PMF 1 if there is no anchorage. If the anchorage appears small compared to the size of the charger, or is damaged, select PMF 2.

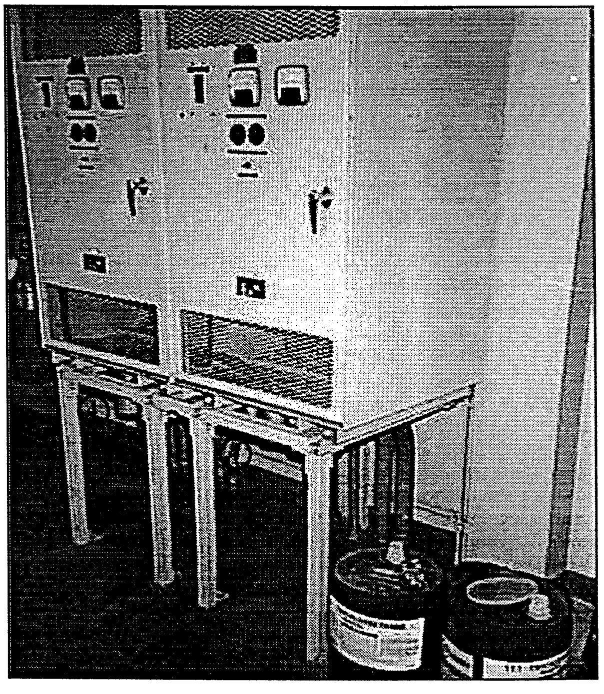
3 If the unit is mounted on thin gage sheet metal channels, or other sections which are weak in the lateral direction, select PMF 3.

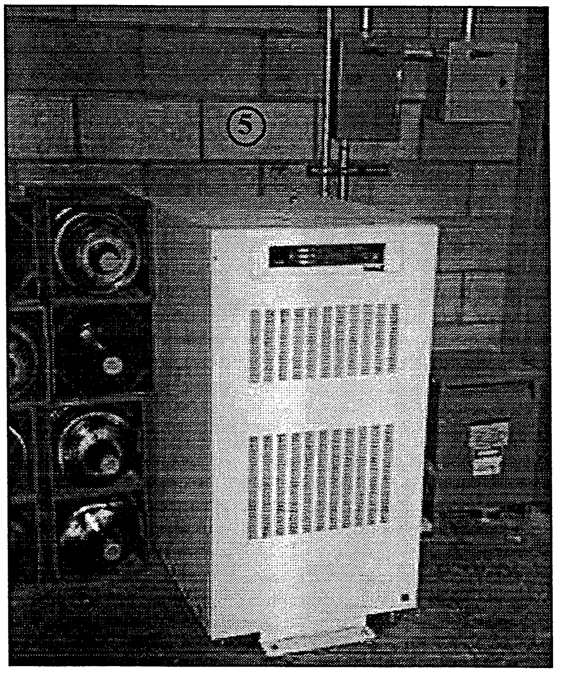
4 Where there is no definite load path to the anchorage or it appears to be weak (as in the lower left hand photo), select PMF 4.

5 If large items, such as non-structural walls, could fall and impact the charger, PMF 5 should be selected.

6 For other conditions that the reviewer believes could inhibit charger function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Rapid Visual Screening Score Sheet | EL-08

Generators

ID Number ______________________________

Comments ______________________________

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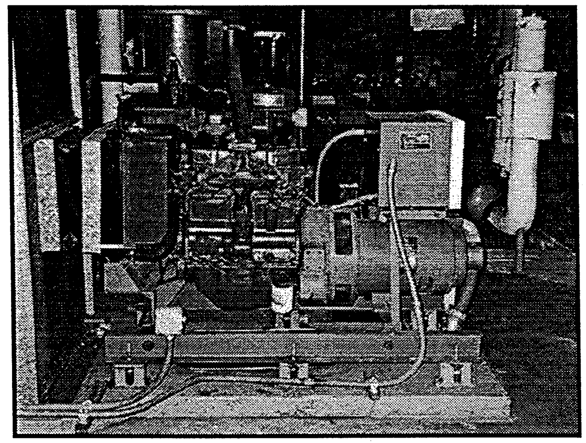


Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Generators

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		5.6	5.1	4.7	4.2	3.8
PMF	1. No anchorage	1.6	1.6	1.6	1.6	1.6
PMF	2. "Poor" anchorage	1.4	1.4	1.4	1.4	1.4
PMF	3. Vibration isolator concerns	1.4	1.4	1.4	1.4	1.4
PMF	4. Rigid attachment concerns	2.0	2.0	2.0	2.0	2.0
PMF	5. Driver/generator diff. displacement	2.0	2.0	2.0	2.0	2.0
PMF	6. Interaction concerns	1.4	1.4	1.4	1.4	1.4
PMF	7. Other ______________					
Final Score = Basic Score - **highest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

1, 2 Select PMF 1 if there is no anchorage. If the anchorage appears small compared to the size of the generator, or is damaged, select PMF 2.

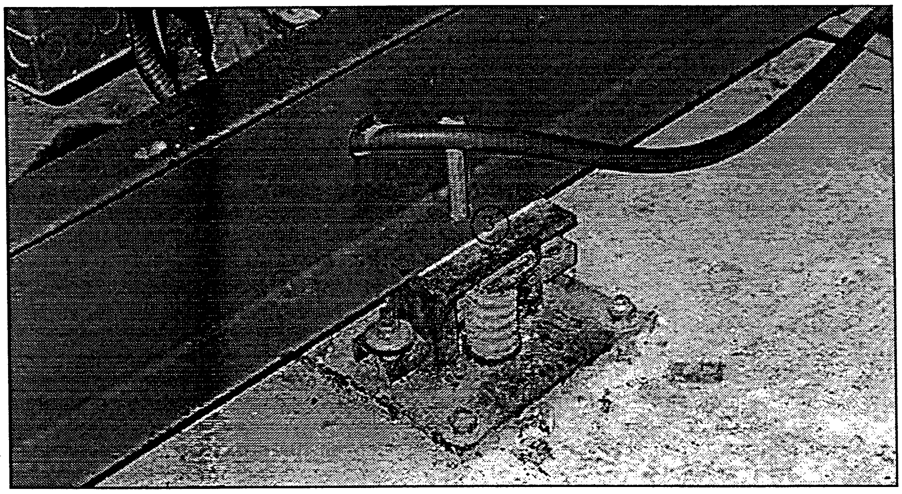
3 Where vibration isolators are used there should be lateral and uplift restraints. If no restraints exist, or they appear to be inadequate, select PMF 3.

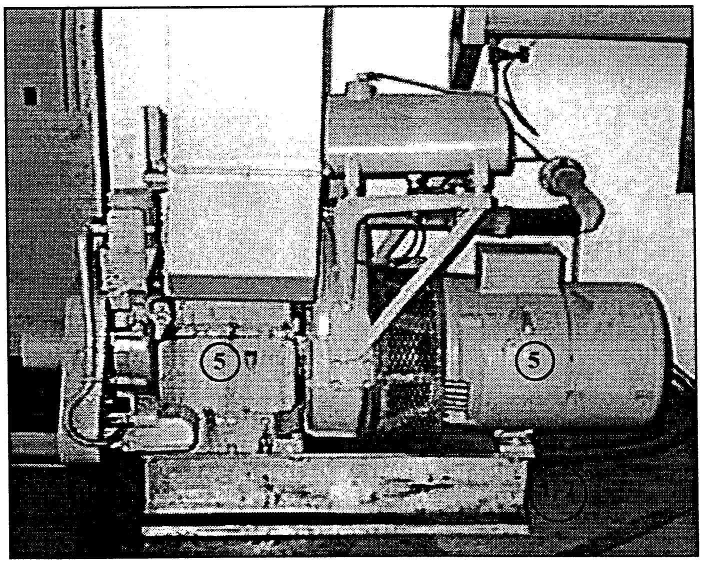
4 If attached conduits do not have adequate flexibility to accommodate potential generator motions, select PMF 4.

5 As shown below, the driver and motor should be mounted to the same skid, if they aren't, select PMF 5.

6 If large items, such as non-structural walls, could fall and impact the generator, PMF 6 should be selected.

7 For other conditions that the reviewer believes could inhibit generator function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





Rapid Visual Screening Score Sheet — FP-01

Fire Protection Equipment

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ______________________

Comments ______________________

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Fire Alarm Pull Station

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. The pull stations are not marked, or access is blocked.	5	5	5	5	5
M	2. Other______________________					
F	3. Other______________________					
	Final Score = Basic Score - **largest applicable** PMF					

Detectors, monitors, alarms and sensors

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. There is no regular inspection of the devices to insure proper function.	4	4	4	4	4
M	2. The devices are not properly mounted and could fall in an earthquake.	1.5	2.0	2.4	2.9	3.3
F	3. Other______________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs) - Pull Stations

1 If access is blocked, personnel don't know locations of pull boxes, or other reasons raise doubts about the ability to use pull boxes, select PMF 1.

2-3 For other conditions that the reviewer believes could inhibit function following an earthquake, (e.g., history of problems with the duct) assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Performance Modification Factors (PMFs) - Detectors, Sensors, and Others

1 If there is any question regarding maintenance of the sensors, monitors, etc., select PMF 1.

2 If the unit is not supported (alarms with no anchors) or if there are any reasons to question the structural capacity of the support system, select PMF 2.

3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | FP-02

Fire Protection Equipment

Earthquake Load Level (circle one letter)

	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ________________

Comments ________________

Hand-held fire extinguishers and Fire hose stations

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. There is no regular inspection or maintenance of the units to assure reliable function.	4	4	4	4	4
M	2. Units are not accessible.	2.2	2.8	3.1	3.7	4.0
F	3. Other________________					
	Final Score = Basic Score - **largest applicable** PMF					

Fuel Shutoff Valve

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	7.2	6.6	6.3	5.7	5.4
P	1. There is no regular inspection of the valve to ensure proper function.	2	2	2	2	2
M	2. If manually controlled, unit is not accessible, or personnel are not trained in its use.	5	5	5	5	5
F	3. Other________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Fire Protection Equipment (continued)

Duct fire/smoke dampers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

Description		A	B	C	D	E
Basic Score		6	6	6	6	6
P	1. There is no regular inspection of the devices to insure proper function.	3	3	3	3	3
M	2. Other __________					
F	3. Other __________					
Final Score = Basic Score - **largest applicable** PMF						

Performance Modification Factors (PMFs) - All Items on Scoresheet FP-02

1 If there is any question regarding maintenance of the items, select PMF 1.

2 If there is any reason to question the ability of personnel to access the item (location not known, located in difficult to reach spot, personnel not trained to use, etc.), select PMF 2.

3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | FP-03

Fire Protection Piping (Includes Sprinkler Heads)

ID Number ____________________________

Comments ____________________________

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Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.0**	**4.4**	**4.1**	**3.5**	**3.2**
	1. No lateral support - possible falling of pipe.	0.8	0.8	0.8	0.8	0.8
P	2. Questionable vertical support system for pipe.	1.7	1.7	1.7	1.7	1.7
M	3. Short stiff branches attached to long flexible headers.	0.8	0.8	0.8	0.8	0.8
F	4. Inadequate flexibility where piping crosses seismic gaps.	0.9	0.9	0.9	0.9	0.9
	5. Sprinkler heads could be damaged on impact.	2.1	2.1	2.1	2.0	2.0
	6. Sprinkler heads are part of unbraced suspended ceiling.	2.4	2.4	2.3	2.3	2.3
	7. Other ____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Page 1 of 2

Performance Modification Factors (PMFs)

1 If the pipe has no lateral supports, such as U-bolts, and no lateral stops, and could slide off of the support during an earthquake, select PMF 1. This is usually for relatively long straight runs.

2 Several support conditions represent a falling hazard for piping in an earthquake. Examples include use of shotpins for anchorage of the supports, C-clamps that an loosen and lose their friction connection, and brittle piping connections such as bell and spigot joints that can detach due to shaking (they should be supported on each side of the connection). If these or other situations exist that could lead to a pipe falling off its support during an earthquake, select PMF 2.

3 Rigid branch lines on flexible headers can attract significant load during a seismic event. This can lead to a damage and leakage at the branch / header interface. If this condition exists for the run of pipe, select PMF 3.

4 Pipe must have flexibility to accomodate differential motions at its anchor points. Differential motion can be encountered where pipe spans a seismic gap, a building crossing, etc. If the pipe is not able to withstand significant differential displacement of its supports, select PMF 4.

5 If sprinkler heads are close to large structural elements that could damage them upon impact, select PMF 5.

6 If sprinkler heads are part of a suspended ceiling that is not braced to resist lateral motions, select PMF 6.

7 For other conditions that the reviewer believes could inhibit function following an earthquake, (e.g., a history of problems with this piping system) assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | HV-01

Fans

ID Number ______________________

Comments ______________________

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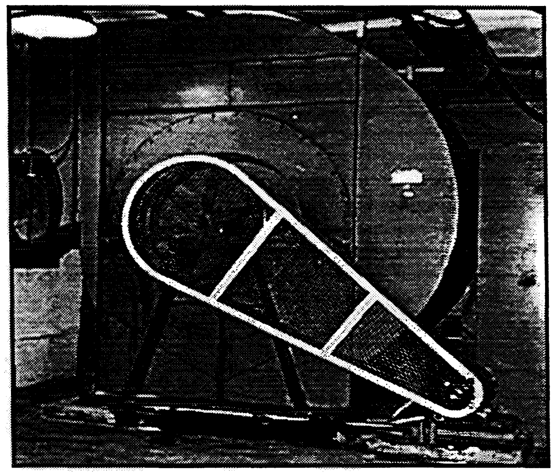


Earthquake Load Level (circle one letter)

	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Fans

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.0**	**4.4**	**4.1**	**3.5**	**3.2**
PMF	1. No anchorage	1.4	1.4	1.4	1.4	1.4
	2. "Poor" anchorage	1.1	1.1	1.1	1.1	1.1
	3. Vibration isolator concerns	1.7	1.7	1.7	1.7	1.6
	4. Fan/motor diff. displacement	0.9	0.9	0.9	0.9	0.9
	5. Duct support concerns	0.8	0.8	0.8	0.8	0.8
	6. Rigid attachment concerns	1.1	1.1	1.1	1.1	1.1
	7. Interaction concerns	1.4	1.4	1.4	1.4	1.4
	8. Other ______					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

1, 2 Often, as shown below, the fan, the motor or both are anchored to a skid which is in turn anchored to a pad or slab. If there is no anchorage for the fan or motor, select PMF 1. If the anchorage is damaged or appears small compared to the size of the unit, select PMF 2.

3 The vibration isolators shown below have restraints to allow vibration, but restrict lateral motion and uplift. If the fan has vibration isolators but has no restraints, or the restraints appear to be inadequate, select PMF 3.

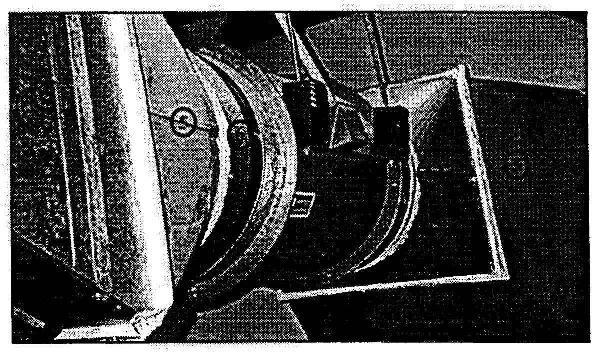
4 Differential displacement of the motor and the fan can cause damage to the fan. This can be caused by anchoring the two items to different pads or skids. This is especially a problem with long drive shafts. If there is a potential for differential displacement, select PMF 4.

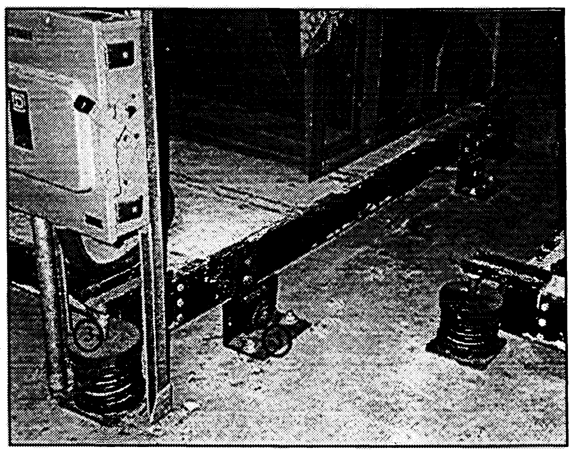
5 Attached ducting must be properly supported to prevent loads from being transferred to the fans. If the duct has a bellows connection, it should be adequately supported on both sides of the flexible connection. If there is a question about the adequacy of the duct supports, select PMF 5.

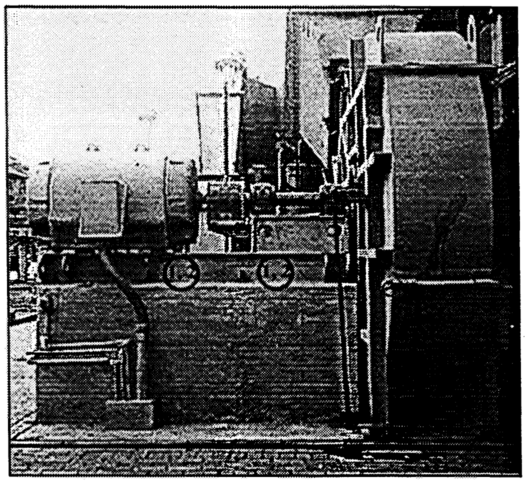
6 The photo below shows an in-line fan with flexible connections to the duct. If ducts or other elements are rigidly attached to a fan (not including small conduit), select PMF 6.

7 If large items, such as non-structural walls, could fall and impair the function of the fan, select PMF 7.

8 For other conditions that the reviewer believes could inhibit fan function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Rapid Visual Screening Score Sheet | HV-02

Air Handlers

ID Number ______________________

Comments ______________________

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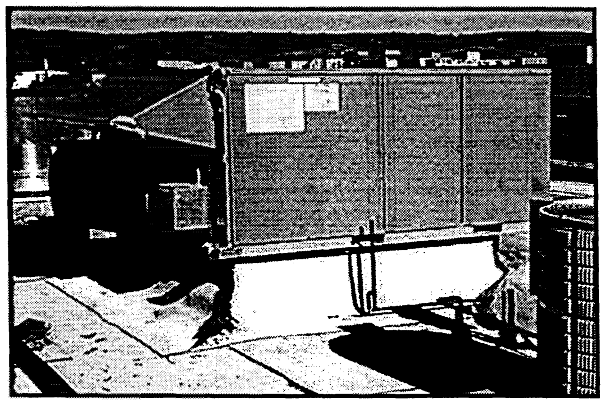


Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Air Handlers

(circle a Basic Score and <u>all</u> PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.2**	**4.7**	**4.3**	**3.8**	**3.4**
PMF	1. No anchorage	1.7	1.7	1.7	1.7	1.7
	2. "Poor" anchorage	1.4	1.4	1.4	1.4	1.4
	3. Vibration isolator concerns	1.4	1.4	1.4	1.4	1.4
	4. Duct support concerns	0.7	0.7	0.7	0.7	0.7
	5. Rigid attachment concerns	2.0	2.0	2.0	2.0	1.9
	6. Interaction concerns	1.2	1.2	1.2	1.2	1.2
	7. Other ______					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

1, 2 If there is no anchorage for the unit, select PMF 1. If the anchorage is damaged or appears small compared to the size of the unit, select PMF 2.

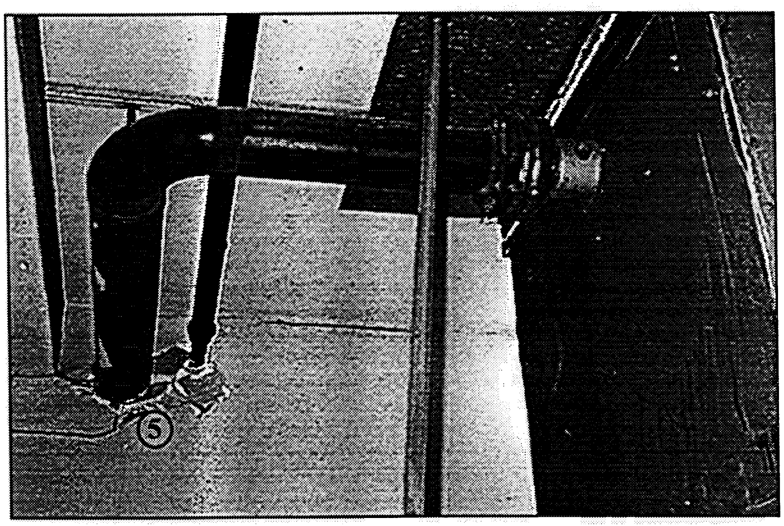
3 The vibration isolators shown below have no restraints to restrict lateral motion or uplift. If the air handler has vibration isolators but has no restraints, or the restraints appear to be inadequate, select PMF 3.

4 Attached ducting must be properly supported to prevent loads from being transferred to the unit. Ducts with flexible bellows connections must be supported on each side of the bellows. If there is a question about the adequacy of the duct supports, select PMF 4.

5 The photo below shows a rigidly attached pipe which has damaged the wall due to the unit's movement. If rigid attachments such as this exist, select PMF 5.

6 If large, nearby items could fall and impact the air handling unit, or other impact concerns exist, select PMF 6.

7 For other conditions that the reviewer believes could inhibit air handler function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.



Rapid Visual Screening Score Sheet | HV-03

Chillers

ID Number ______________________________

Comments ______________________________

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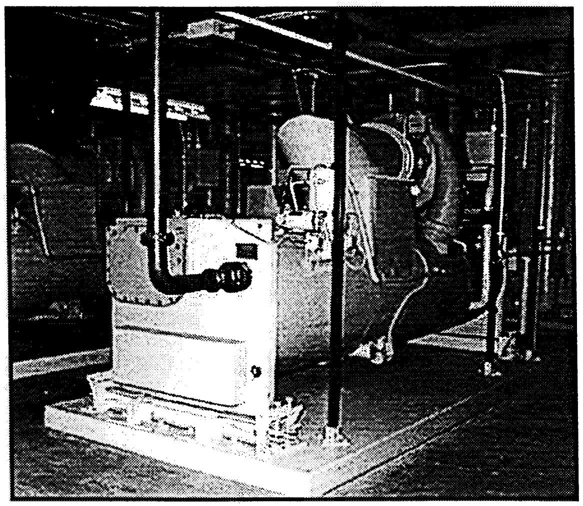


Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Chillers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.4**	**4.8**	**4.5**	**3.9**	**3.6**
	1. No anchorage	1.2	1.2	1.2	1.2	1.2
P	2. "Poor" anchorage	0.9	0.9	0.9	0.9	0.9
M	3. Vibration isolator concerns	1.8	1.8	1.8	1.8	1.8
F	4. Piping support concerns	1.0	1.0	1.0	1.0	1.0
	5. Interaction concerns	0.7	0.7	0.7	0.7	0.7
	6. Other ____________					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

1, 2 Select PMF 1 if there is no anchorage. If the anchorage appears small compared to the size of the chiller, or is damaged, select PMF 2.

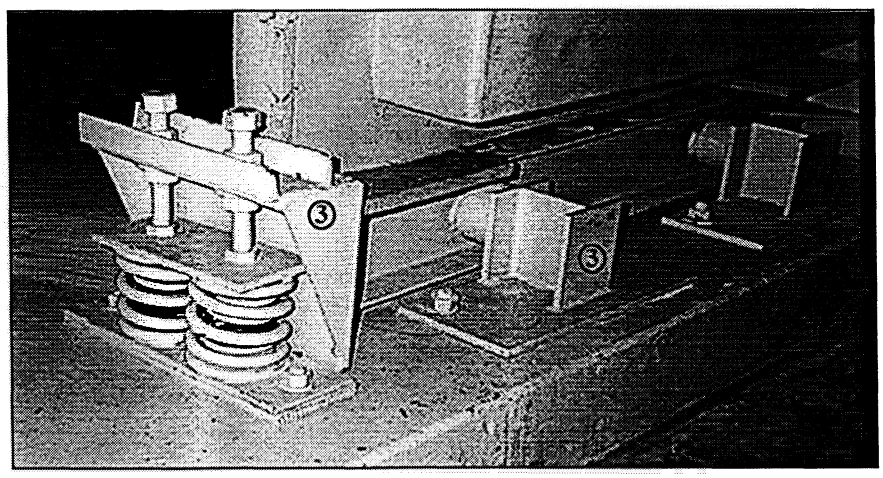
3 The vibration isolators shown below have restraints to allow vibration, but restrict lateral motion and uplift. If the fan has vibration isolators but has no restraints, or the restraints appear to be inadequate, select PMF 3.

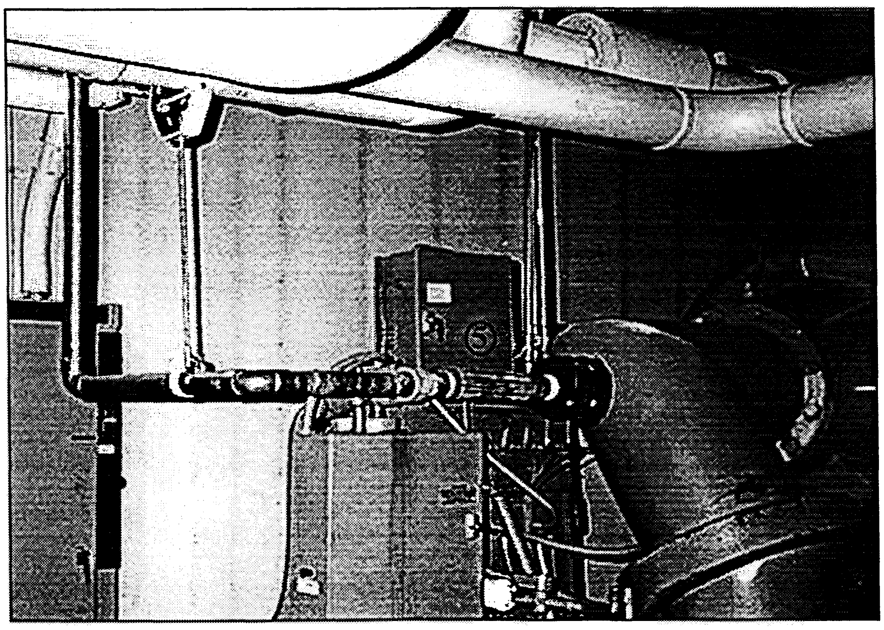
4 If the unit is mounted on channel or other sections which are weak in the lateral direction, select PMF 4.

5 Attached piping should be well supported to prevent excessive load transfer to the chiller. If long, unsupported runs of piping terminate at the chiller, select PMF 5.

6 If large items, such as non-structural walls, could fall and impact the chiller, PMF 6 should be selected.

7 For other conditions that the reviewer believes could inhibit chiller function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





Rapid Visual Screening Score Sheet — MB-01

Miscellaneous Building Components

Earthquake Load Level (circle one letter)

	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ____________________

Comments ____________________

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Raised Access Floors

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6.0	6.0	6.0	6.0	6.0
P	1. There is no bracing, or other means, present to prevent excessive lateral motions.	2.0	2.5	3.0	3.5	4.5
M	2. Other____________________					
F	3. Other____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Suspended Ceilings (and associated lighting)

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6.0	6.0	6.0	6.0	6.0
P	1. Where fallen ceiling tiles and frames could damage equipment, endanger workers or limit egress, there are no diagonal sway braces.	2.0	2.5	3.0	3.5	4.5
M	2. Light fixtures are not securely, independently anchored.	2.0	2.5	3.0	3.5	4.5
F	3. Other____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet — MB-02

Miscellaneous Building Components

Earthquake Load Level
(circle one letter)

ZONE	NEHRP	UBC	Level
Z	1-3	1	A
O	4-5	2	B
N	6	3	C
E	7	4	D

ID Number ______________________

Comments______________________

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Elevators and Elevator Derailment Detectors

(circle a Basic Score and all PMFs that apply - use the column indicated by the Earthquake Load Level)

Description		A	B	C	D	E
Basic Score		**6**	**6**	**6**	**6**	**6**
P	1. Cabs and counterweights are equipped with devices to detect detachment from rails.	5	5	5	5	5
M	2. Sheaves have guards to prevent slipping off of cables in an earthquake.	1.8	2.3	2.7	3.2	3.6
F	3. Qualified personnel are not available to inspect elevators and allow restart in an earthquake.	5	5	5	5	5
	4. Other______________________					
Final Score = Basic Score - **largest applicable** PMF						

Performance Modification Factors (PMFs) - Elevator Systems

1 Detection devices are required in some states to automatically shut down an elevator if the motion of the cables is significant in an earthquake. If you do not have such a system, select PMF 1.

2 Movement of cables in an earthquake has caused them to "bounce" off of sheaves. If you do not have guards to prevent this from occurring, selecting PMF 2.

3 If the system shuts down, even with no damage, an inspection should be performed before the elevator can be used again. There may be significant delays in service and interruption in business in the event of a major earthquake. Select PMF3 if this is considered to be a likely problem.

4 For any ther conditions that the reviewer believes could inhibit function or restart following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | MC-01

Miscellaneous Computer Equipment

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ____________________

Comments ____________________

Mainframes and Communications Control Equipment

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	2.4	3.0	3.3	3.9	4.2
M	2. There is a significant interaction hazard from something falling onto this equipment.	2.2	2.7	3.1	3.6	4.0
F	3. Other ____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Mini/microcomputers and peripherals (tape drive, disc drives, printers, monitors, etc.)

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. The units are not attached to tables or desks to prevent them from sliding and falling.	2.7	3.2	3.6	4.1	4.5
M	2. The tables or desks are unstable and likely to collapse.	1.2	1.8	2.1	2.7	3.0
F	3. The units are resting on the floor in such a way that overturning is likely.	2.2	2.7	3.1	3.6	4.0
	4. There is a significant interaction hazard from something falling onto this equipment.	1.8	2.3	2.7	3.2	3.6
	5. Other ____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Performance Modification Factors (PMFs) - Mainframes and Communications Control Equipment

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

1 If the unit is unrestrained and unanchored and is tall and slender (such that it is likely to tip rather than slide), select PMF 1.

2 If there are nearby hazards than can fall onto the equipment and cause damage (heavy light fixtures, bookcases, etc.) select PMF 2.

3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Performance Modification Factors (PMFs) - Mini/microcomputers and peripherals

1 If the units are not tied down and could slide off the table or desk onto the floor, select PMF 1.

2 If the table or desk appears questionable, select PMF 2.

3 If the units are on the floor and are positioned such that they can tip over, select PMF 3.

4 If there are nearby hazards than can fall onto the equipment and cause damage (heavy light fixtures, bookcases, etc.) select PMF 4.

5 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | MC-02

Miscellaneous Computer Equipment

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ______________________

Comments ______________________

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Media Racks

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	1.8	2.3	2.7	3.2	3.6
M	2. The media are not secured within the rack to prevent items from falling.	2.7	3.2	3.6	4.1	4.5
F	3. Other ______________________					
	Final Score = Basic Score - **largest applicable** PMF					

Document Handling Equipment

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	1.8	2.3	2.7	3.2	3.6
M	2. Other ______________________					
F	3. Other ______________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs) - Media Racks

1 If the unit is unrestrained and unanchored and is tall and slender (such that it is likely to tip rather than slide), select PMF 1.

2 If the media are not secured within the rack to prevent items from falling and being damaged, select PMF 2.

3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Performance Modification Factors (PMFs) - Document Handling Equipment

1 If the unit is unrestrained and unanchored and is tall and slender (such that it is likely to tip rather than slide), select PMF 1.

2, 3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet — MD-01

Medical Equipment

Earthquake Load Level (circle one letter)

	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ______________________

Comments ______________________

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Medical Lab and Medical Unit Equipment

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

Description		A	B	C	D	E
Basic Score		**6**	**6**	**6**	**6**	**6**
P	1. Medical lab items are not secured to counters and tables.	2.2	2.7	3.1	3.6	4.0
M	2. Medical lab items are stored on counters, tables, or carts that are likely to collapse.	1.8	2.3	2.7	3.2	3.6
F	3. Other ______________________					
Final Score = Basic Score - **largest applicable** PMF						

Blood Bank Refrigerators

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

Description		A	B	C	D	E
Basic Score		**6**	**6**	**6**	**6**	**6**
P	1. There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	1.8	2.3	2.7	3.2	3.6
M	2. Other ______________________					
F	3. Other ______________________					
Final Score = Basic Score - **largest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs) - Medical Lab and Medical Unit Equipment

1 If items are unrestrained and can slide and fall in an earthquake, select PMF 1.

2 If the table or other items holding the equipment does not appear to be strong enough to resist lateral loads from an earthquake without collapsing, select PMF 2.

3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Performance Modification Factors (PMFs) - Blood Bank Refrigerators

1 If the unit is unrestrained and unanchored and is tall and slender (such that it is likely to tip rather than slide), select PMF 1.

2, 3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | ME-01

Miscellaneous Electrical Equipment

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ____________________

Comments ____________________

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Power Transfer Equipment

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level)

	Description	A	B	C	D	E
	Basic Score	**5.7**	**5.2**	**4.8**	**4.3**	**3.9**
P	1. There are no restraints or anchorage to prevent the unit from overturning.	2.4	2.4	2.4	2.4	2.4
M	2. Other____________________					
F	3. Other____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Portable Generators

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level)

	Description	A	B	C	D	E
	Basic Score	**6**	**6**	**6**	**6**	**6**
	1. There is no regular inspection or maintenance to assure reliable function of the generators.	1.5	2.0	2.4	2.9	3.3
P	2. There are not personnel on hand who know how to operate the generators.	5	5	5	5	5
M	3. There is not a reliable fuel supply on hand for the generator.	5	5	5	5	5
F	4. The generator is stored in an area that will be difficult to access during an emergency situation.	5	5	5	5	5
	5. Other____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs) - Power Transfer Equipment

1 If the unit is unrestrained and unanchored and is tall and slender (such that it is likely to tip rather than slide), select PMF 1.

2,3 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Performance Modification Factors (PMFs) - Portable Generators

1 If the unit is not routinely started up, inspected, and maintained on a regular schedule, select PMF 1.

2 If the unit requires special expertise to operate and that expertise is often or typically not available at the site, select PMF 2.

3 If there is not a reliable fuel supply on hand for the generator, select PMF 3. This includes situations where power may be required to get fuel to the generator (e.g. fuel transfer pumps, etc.)

4 If the generator is stored in an area that will be difficult to access during an emergency situation., select PMF 4.

5 For other conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | ME-02

Miscellaneous Electrical Equipment

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ____________

Comments ____________

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Stairway Emergency Lighting

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**6**	**6**	**6**	**6**	**6**
P	1. There is no regular inspection or maintenance of the lighting units to assure reliable function.	1.5	2.0	2.4	2.9	3.3
M	2. The units are not securely mounted to a wall or frame and could fall in an earthquake.	2.7	3.2	3.6	4.1	4.5
F	3. Other____________					
Final Score = Basic Score - **largest applicable** PMF						

Temporary Lights (e.g., flashlights, lanterns, etc.)

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**6**	**6**	**6**	**6**	**6**
P	1. There is no regular inspection or maintenance of the lighting units to assure reliable function.	1.5	2.0	2.4	2.9	3.3
M	2. The lights are not stored in a readily accessible area known to the personnel who need them.	5	5	5	5	5
F	3. Other____________					
Final Score = Basic Score - **largest applicable** PMF						

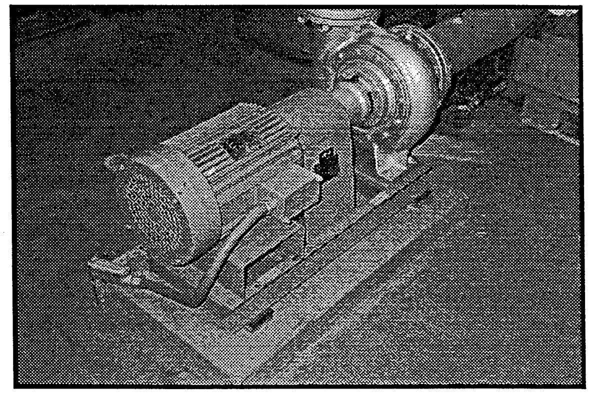
Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Page 1 of 1

Pumps

ID Number ______________________

Comments ______________________



Earthquake Load Level (circle one letter)

ZONE	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Pumps

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	5.1	4.2	3.6	3.2	3.0
PMF	1. No anchorage					
	2. "Poor" anchorage					
	3. Vibration isolator concerns					
	4. Motor/pump displacement	0.6	0.6	0.6	0.6	0.6
	5. Piping support concerns	0.4	0.4	0.4	0.4	0.4
	6. Interaction concerns	0.4	0.4	0.4	0.4	0.4
	7. Other ______					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

1, 2 Select PMF 1 if there is no anchorage from the motor or pump to the skid, or from the skid to the pad. If the anchorage appears small compared to the size of the pump, or is damaged, select PMF 2.

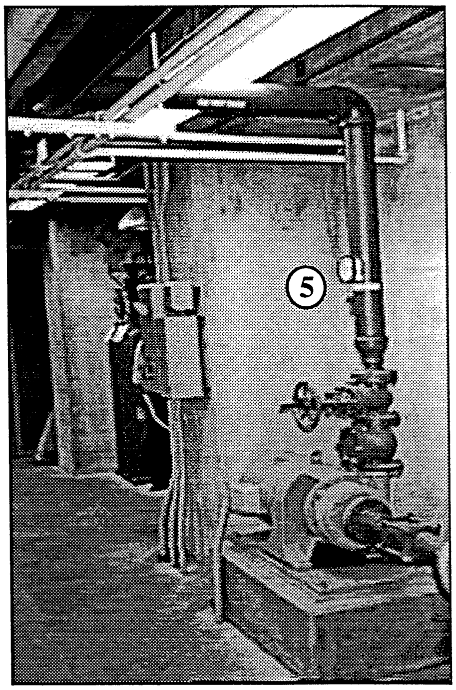
3 Where vibration isolators are used there should be lateral restraints as shown below. If no lateral restraints exist, or they appear to be inadequate, select PMF 3.

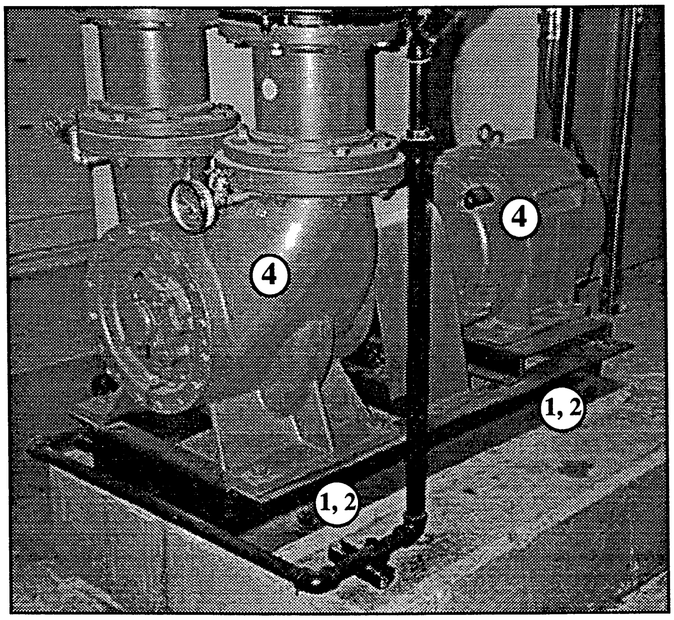
4 The motor and pump should be mounted on a common skid or pad to reduce the risk of differential displacement. Select PMF 4 if they are not.

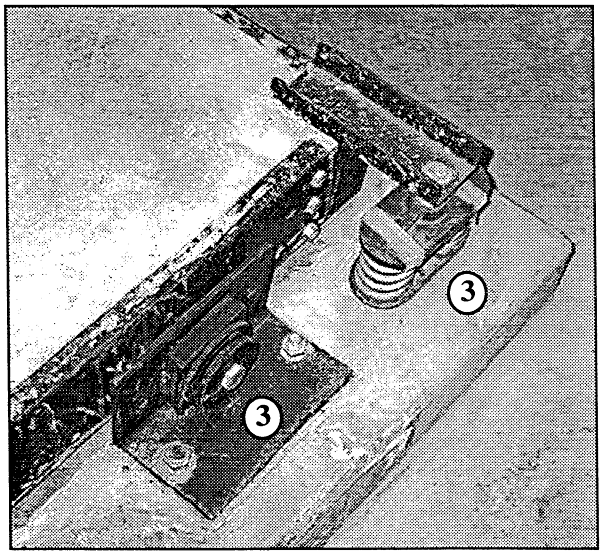
5 Attached piping should be well supported to prevent excessive load transfer to the pump. If long, unsupported runs of piping terminate at the pump, select PMF 5.

6 If large items, such as non-structural walls, could fall and impact the pump, PMF 5 should be selected.

7 For other conditions that the reviewer believes could inhibit pump function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Valves

ID Number ______________________________

Comments ______________________________

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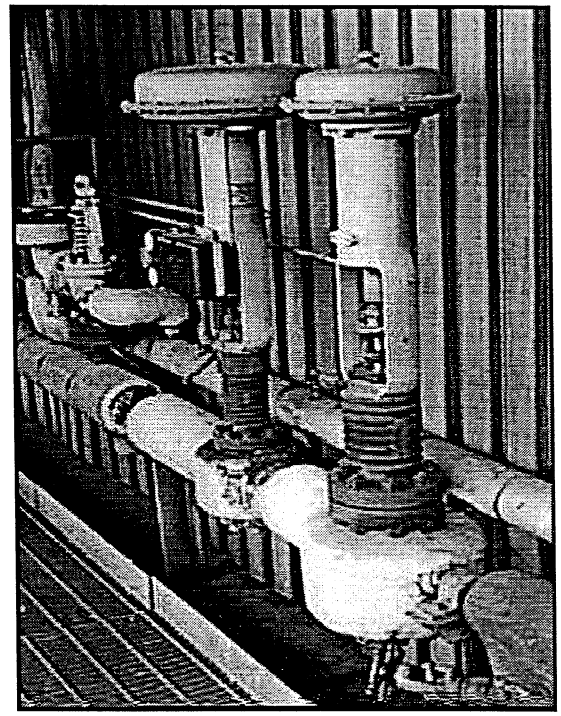


Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Valves

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**7.2**	**6.6**	**6.3**	**5.7**	**5.4**
PMF	1. Cast iron components and impact potential	2.9	2.9	2.9	2.9	2.9
	2. Independent operator support	2.7	2.7	2.7	2.7	2.7
	3. Rigid attachment concerns	3.5	3.5	3.5	3.5	3.5
	4. Interaction concerns	2.3	2.3	2.3	2.3	2.3
	5. Other ______________					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

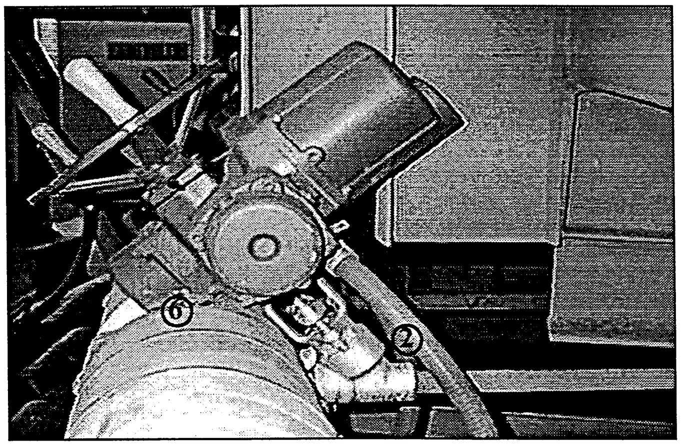
1 Select PMF 1 if you know that the valve yoke or operator are made of cast iron and the valve is mounted on a flexible line where it can move and impact structural members (walls, columns, etc.).

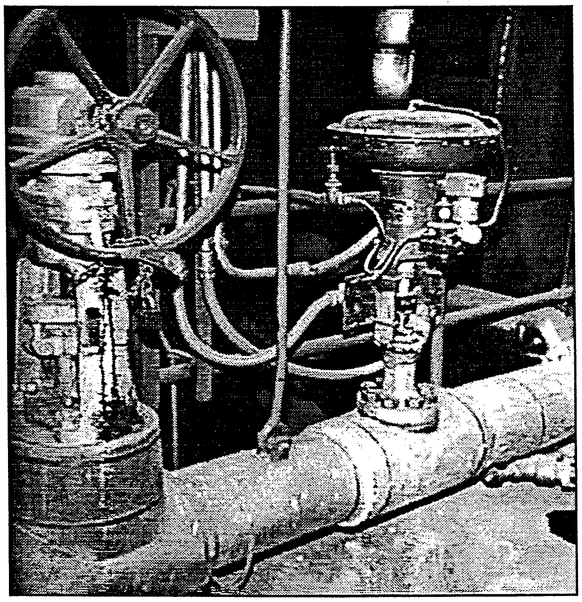
2 The operator should not have a support independent of the overall valve support. If this situation exists, choose PMF 2.

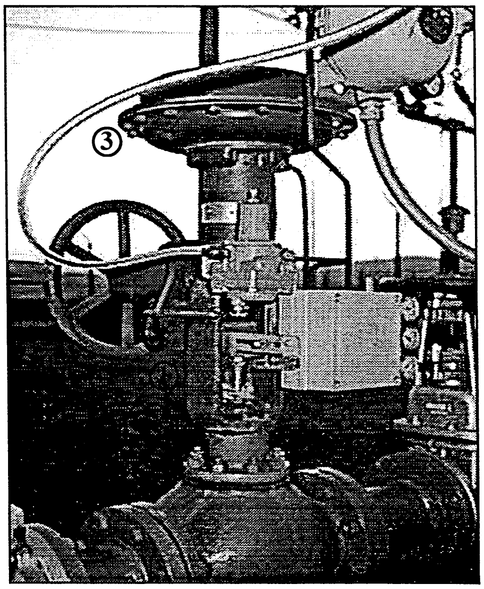
3 Conduit and tubing attached to the valve should be flexible enough so that valve displacement is not hindered. If the attachments are rigid, select PMF 3.

4 If large items, such as non-structural walls, could fall and impact the valve, PMF 4 should be selected. Also, select this PMF if rigid items inhibit valve movement as shown in the photos below.

5 For other conditions that the reviewer believes could inhibit valve function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Rapid Visual Screening Score Sheet | MN-03

Compressors

ID Number ______________________________

Comments ______________________________

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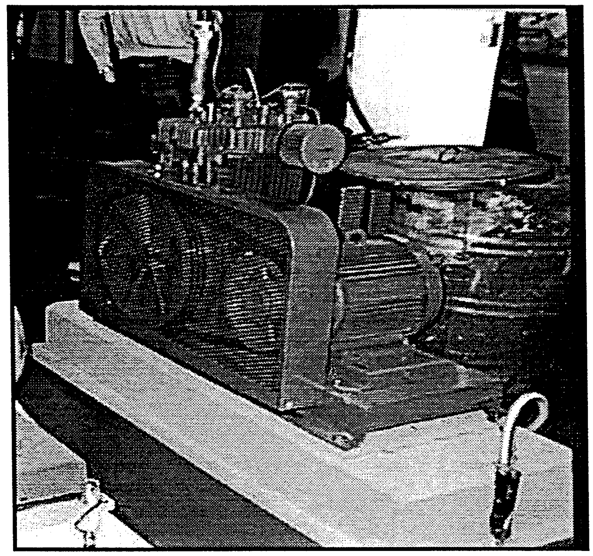


Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Compressors

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6.0**	**5.5**	**5.1**	**4.6**	**4.2**
PMF	1. No anchorage	2.7	2.7	2.7	2.7	2.7
	2. "Poor" anchorage	2.4	2.4	2.4	2.4	2.4
	3. Vibration isolator concerns	1.8	1.8	1.8	1.8	1.8
	4. Rigid attachment concerns	1.8	1.8	1.8	1.8	1.8
	5. Interaction concerns	1.3	1.3	1.3	1.3	1.3
	6. Other ____________					
	Final Score = Basic Score - **highest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Performance Modification Factors (PMFs)

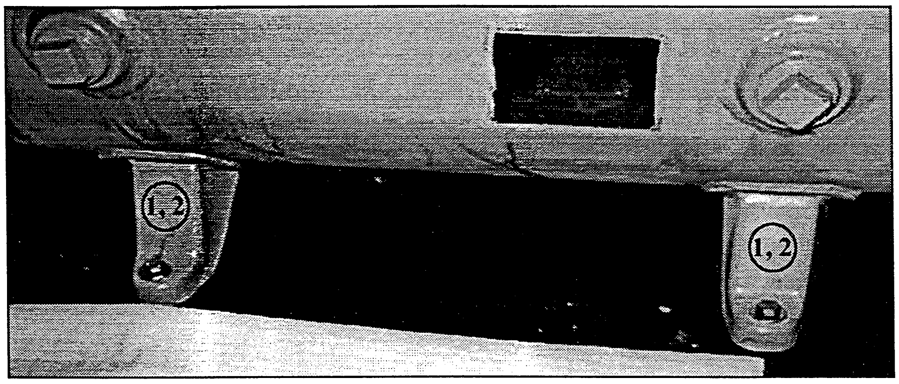
1, 2 Select PMF 1 if there is no anchorage. If the anchorage appears small compared to the size of the compressor, or is damaged, select PMF 2.

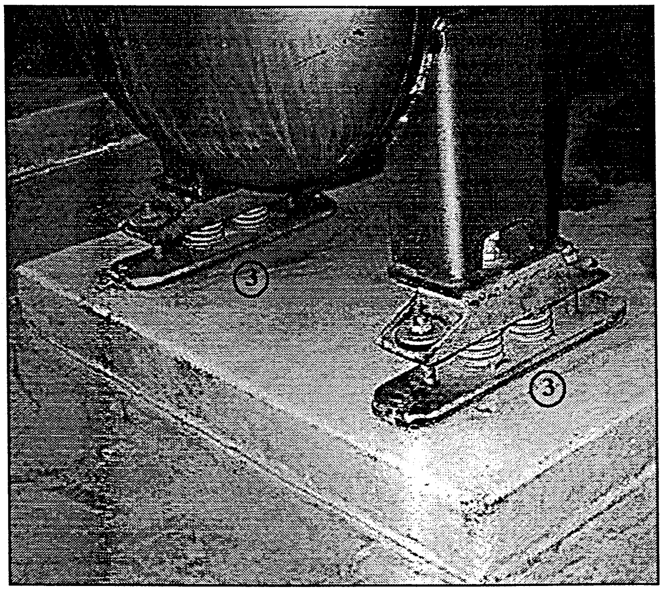
3 Where vibration isolators are used there should be lateral and uplift restraints. If no restraints exist, or they appear to be inadequate, select PMF 3.

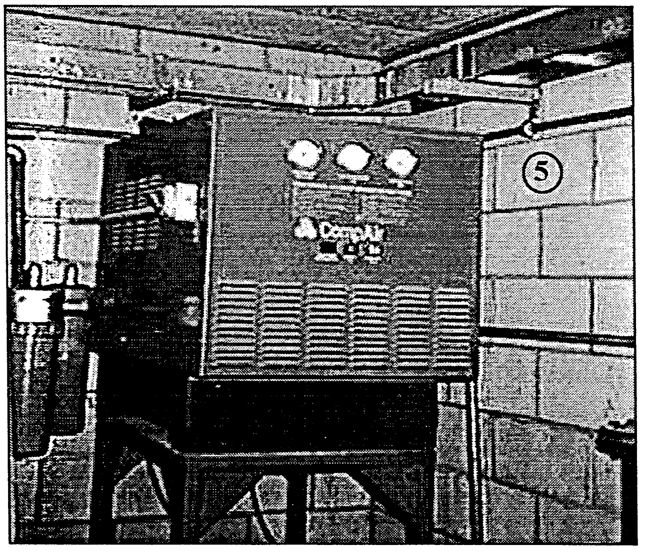
4 If attached conduits or pipes are do not have enough flexibility to accommodate potential compressor displacement, select PMF 4.

5 If large items, such as non-structural walls, could fall and impact the compressor, PMF 5 should be selected.

6 For other conditions that the reviewer believes could inhibit compressor function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Rapid Visual Screening Score Sheet	MN-04

Cooling Towers

ID Number ______________________

Comments ______________________

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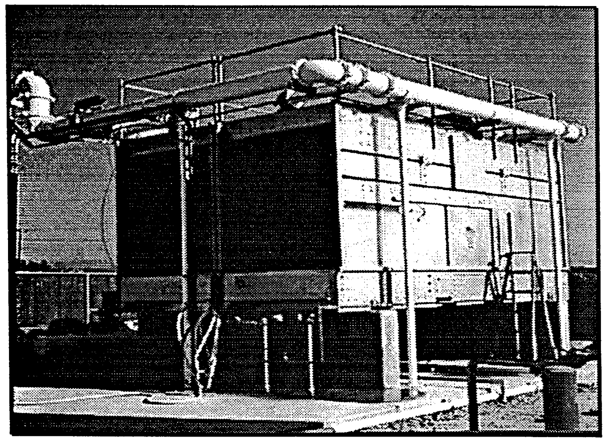

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Cooling Towers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6**	**6**	**6**	**6**	**6**
P	1. There are signs of deterioration on the structural members.	2.7	3.2	3.6	4.1	4.5
M	2. There is not a regular inspection program for this unit.	1.8	2.3	2.7	3.2	3.6
F	3. Mounted on vibration isolators without lateral or uplift restraints.	2.7	3.2	3.6	4.1	4.5
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs)

1 Cooling tower damage for larger wood cooling towers in earthquakes has mainly been on units that have deteriorated. If structural items appear to require repair, exist select PMF 1.

2 A program of regular inspections can prevent and identify potential problems. If there is no such program for the cooling tower, select PMF 2.

3 Units mounted on vibration isolators need lateral and uplift restraints to prevent dismount. If there are no restraints, or they appear to be inadequate, select PMF 3.

4 For other conditions that the reviewer believes could inhibit compressor function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | MN-05

Boilers

ID Number ____________________

Comments ____________________

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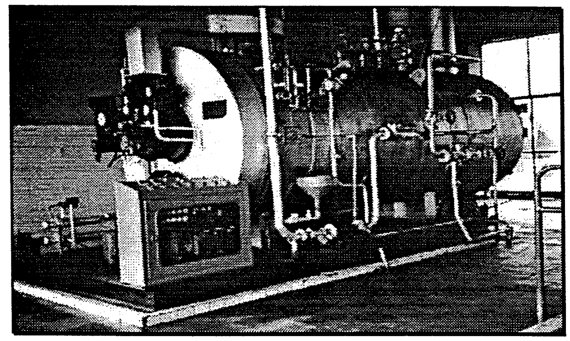

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Boilers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	6	6	6	6	6
P	1. There is no anchorage or the anchorage is in poor condition (e.g., corrosion, cracking, etc.).	2.4	3.0	3.3	3.9	4.2
M	2. Attached items do not have adequate flexibility to accomodate potential seismic deflections.	2.2	2.7	3.1	3.6	4.0
F	3. Mounted on vibration isolators without lateral or uplift restraints.	2.4	3.0	3.3	3.9	4.2
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs)

1 Boilers must be anchored to their suppots. The anchorage should be free of heavy corrosion. There should not be significant concrete cracking around the bolts. If these, or other conditions that appear to require repair, exist select PMF 1.

2 Some amount of motion from seismic loads is common. The attached components must be able to withstand this motion and remain intact. If they cannot, select PMF 2.

3 Units mounted on vibration isolators need lateral and uplift restraints to prevent dismount. If there are no restraints, or they appear to be inadequate, select PMF 3.

4 For other conditions that the reviewer believes could inhibit compressor function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | OS-01

Off-Site Systems

Earthquake Load Level
(circle one letter)

	NEHRP	UBC	Load Level
Z	1-3	1	A
O	4-5	2	B
N	6	3	C
E	7	4	D

Comments ______________________________

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Off-site Domestic Water

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

Description		A	B	C	D	E
Basic Score		3.7	3.2	2.8	2.3	1.9
P	1.					
M	2.					
F	3.					
Final Score = Basic Score - **largest applicable** PMF						

Off-site Fire Water

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

Description		A	B	C	D	E
Basic Score		3.7	3.2	2.8	2.3	1.9
P	1.					
M	2.					
F	3.					
Final Score = Basic Score - **largest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Off-Site Systems (continued)

Off-site Power

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

Description		A	B	C	D	E
Basic Score		2.6	2.1	1.7	1.2	0.9
P	1.					
M	2.					
F	3.					
Final Score = Basic Score - **largest applicable** PMF						

Off-site Natural Gas

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

Description		A	B	C	D	E
Basic Score		5	5	5	5	5
P	1.					
M	2.					
F	3.					
Final Score = Basic Score - **largest applicable** PMF						

Performance Modification Factors (PMFs) - All Offsite Systems

1, 2, 3 For any conditions that the reviewer believes could inhibit function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet — TC-01

Telecommunications Equipment

Earthquake Load Level (circle one letter)

ZONE	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ______________________

Comments ______________________

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Cable Entrance Facility

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6**	**6**	**6**	**6**	**6**
P	1. The enclosure is in poor condition or has components that obviously require repair.	1.5	2.0	2.4	2.9	3.3
M	2. The cables are in poor condition or obviously require repair.	1.6	2.2	2.5	3.1	3.4
F	3. Not attached to the structure or on "poor" soil.	2.4	3.0	3.3	3.9	4.2
F	4. Other ______________					
	Final Score = Basic Score - **largest applicable** PMF					

Rack Mounted Components

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**4.8**	**4.3**	**3.9**	**3.4**	**3.0**
P	1. The rack is not braced or has no anchorage to prevent overturning.	1.0	1.0	1.0	1.0	1.0
M	2. The components are not securely mounted to the rack.	1.3	1.3	1.3	1.3	1.2
F	3. Other ______________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Page 1 of 1

Rapid Visual Screening Score Sheet — TC-02

Telecommunications Equipment

Earthquake Load Level (circle one letter)

	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ____________________

Comments ____________________

Microwave Systems

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6.5**	**6.0**	**5.6**	**5.1**	**4.7**
P	1. The translation/control equipment is not restrained to prevent overturning.	2.9	2.9	2.9	2.9	2.9
M	2. The tower and attached dish are not structurally adequate to prevent collapse.	2.0	2.0	2.0	2.0	2.0
F	3. Other ____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Telephone and Radio Systems

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6**	**6**	**6**	**6**	**6**
P	1. There is no regular inspection or maintenance of the systems to assure reliable function.	1.8	2.3	2.7	3.2	3.6
M	2. Personnel on hand do not know how to operate the systems.	5	5	5	5	5
F	3. Other ____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Page 1 of 1

Rapid Visual Screening Score Sheet | TK-01

Tanks on Legs and Skirts

ID Number ____________________

Comments ____________________

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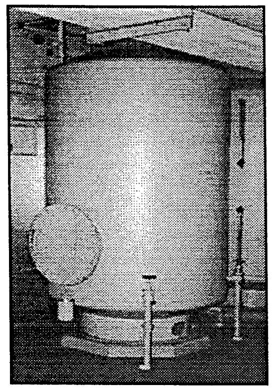

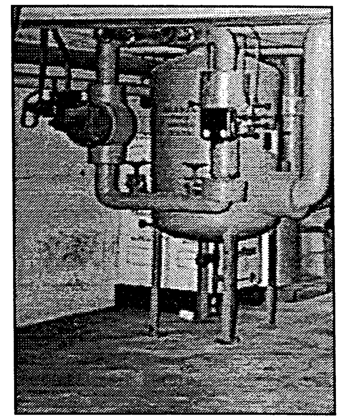

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Tanks on Legs

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**5.0**	**4.4**	**4.1**	**3.5**	**3.2**
P	1. Tank is unanchored or the anchorage is in poor condition.	1.4	1.4	1.4	1.4	1.4
M	2. If anchored to a skid, the skid is unanchored.	0.8	0.8	0.8	0.8	0.8
F	3. Attached piping is too rigid to withstand expected displacement.	1.1	1.1	1.1	1.1	1.1
	4. Legs appear to be undersized for weight of the tank, or skirt has unreinforced opening.	1.1	1.1	1.1	1.1	1.1
	5. Other____________________					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs)

1. Tanks should be anchored and the anchorage should be in good condition (e.g., no heavy corrosion, no significant concrete cracks around the bolts). If not, select PMF 1.
2. If the tank is anchored to a skid and the skid is not anchored, select PMF 2.
3. Even for anchored tanks, there is the potential for significant motion during a seismic event. If the piping attached to the tank is too rigid to survive expected displacement, select PMF 3. An example may be a straight run of pipe from the top of the tank to an anchor point on a pipeway.
4. Supporting legs or skirts may be insufficient to prevent collapse under lateral loads. If tank supports appear inadequate, select PMF 4. This PMF should also be used if the tank has unreinforced openings. This can happen if piping penetrations are not at locations where designed for, and field modifications have been made during installation.
5. For other conditions that the reviewer believes could inhibit tank function following an earthquake (e.g., a history of problems with this tank), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | TK-02

Horizontal Tanks and Heat Exchangers

ID Number ______________________________

Comments ______________________________

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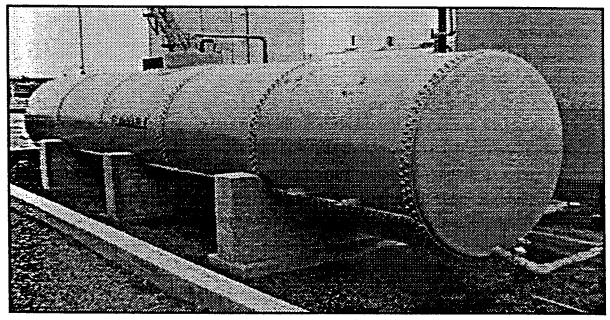

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Horizontal Tanks and Heat Exchangers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6.0**	**5.5**	**5.1**	**4.6**	**4.2**
PMF	1. Vessel is unanchored or the anchorage is in poor condition.	1.8	1.8	1.8	1.8	1.8
	2. Tank is not attached to saddle.	2.2	2.2	2.2	2.2	2.2
	3. Attached piping is too rigid to withstand expected displacement.	2.0	2.0	2.0	2.0	2.0
	4. Shells of stacked heat exchangers are not secured together.	2.4	2.4	2.4	2.4	2.4
	5.					
	Final Score = Basic Score - **largest applicable** PMF					

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Performance Modification Factors (PMFs)

1 Tanks should be anchored and the anchorage should be in good condition (e.g., no heavy corrosion, no significant concrete cracks around the bolts). If not, select PMF 1.

2 If the tank is not attached to its saddle, it could slide or rock in an earthquake. If this motion could cause damage, select PMF 2. Be especially aware of any piping connections, drain taps, etc. that could be impacted by sliding of the tank.

3 Even for anchored tanks, there is the potential for significant motion during a seismic event. If the piping attached to the tank is too rigid to survive expected displacement, select PMF 3. An example may be a straight run of pipe from the top of the tank to an anchor point on a pipeway.

4 Vertically stacked heat exchangers should be positively attached to each other. If they are not, select PMF 4. This may occur when bolts are removed and not reinstalled during maintenance.

5 For other conditions that the reviewer believes could inhibit tank function following an earthquake (e.g., a history of problems with this vessel), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | TK-03

Anchored Vertical Tanks

ID Number ________________________________

Comments ________________________________

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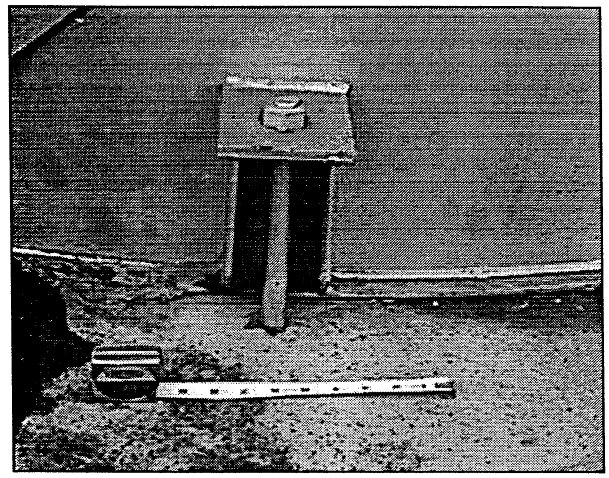


Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Scores and Modifiers - Anchored Vertical Tanks

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**5.2**	**4.7**	**4.3**	**3.8**	**3.4**
	1. The anchorage is in poor condition.	1.7	1.7	1.7	1.7	1.7
P	2. Anchor details are non-ductile or could tear the shell.	1.4	1.4	1.4	1.4	1.4
M	3. Attached piping is too rigid to withstand expected displacement.	1.0	1.0	1.0	1.0	1.0
F	4. Tank is made of stainless steel.	1.7	1.7	1.7	1.7	1.7
	5. Tank is made of fiberglass or similar material.	2.0	2.0	2.0	2.0	1.9
	6. Other ________________________					
Final Score = Basic Score - **largest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Page 1 of 2

Performance Modification Factors (PMFs)

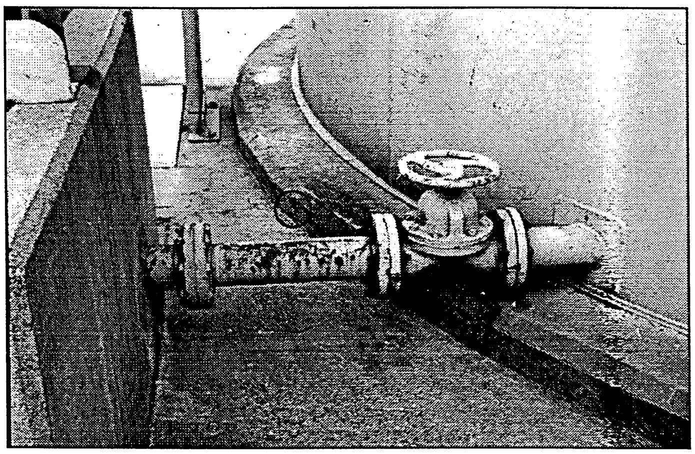
1 Tanks should be anchored and the anchorage should be in good condition (e.g., no heavy corrosion, no significant concrete cracks around the bolts). If not, select PMF 1.

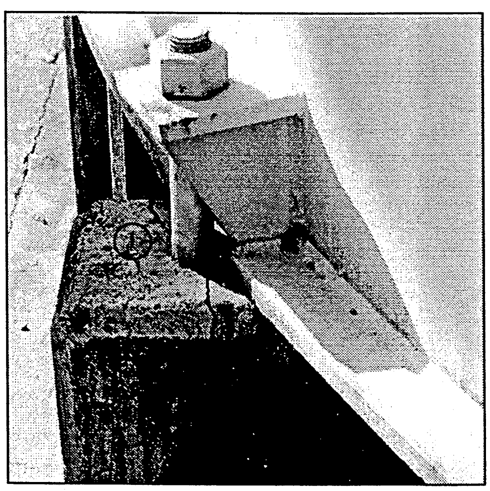
2 Poor connection details include anchors clipped to the bottom plate of the tank and chair connections with unusually short chairs (as shown in the sketches below). If these or other suspect details exist, select PMF 2.

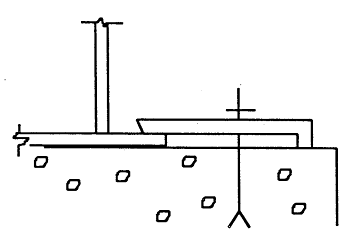
3 Even for anchored tanks, there is the potential for displacement during a seismic event. If the piping attached to the tank is too rigid to survive this much displacement, select PMF 3. Note that this is more of a concern with rigid piping from the top of an anchored tank.

4,5 Select the appropriate PMF if the material used is either stainless steel (likely to be thin walled) or fiber reinforced plastic (Fiberglass).

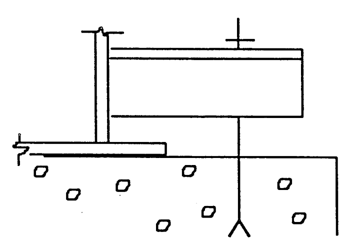
6 For other conditions that the reviewer believes could inhibit tank function following an earthquake (e.g., a history of problems with this tank), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.







Anchor clipped to bottom plate



Short chair height.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet — TK-04

Storage Drums and Cylinders

Earthquake Load Level (circle one letter)

	NEHRP	UBC	Location in Building: Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

ID Number ______________________

Comments ______________________

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Scores and Modifiers

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
	Basic Score	**6.5**	**6.0**	**5.6**	**5.0**	**4.7**
P	1. The units are not restrained with straps to keep them from overturning.	2.5	2.5	2.5	2.5	2.5
M	2. The drums are stacked very high on pallets.	2.7	2.7	2.7	2.7	2.7
F	3. Other					
	Final Score = Basic Score - **largest applicable** PMF					

Performance Modification Factors (PMFs)

1 If possible, storage drums and cylinders should be restrained (with straps or other devices) to prevent them from overturning. If no overturning prevention is provided select PMF 1.

2 If drums are stacked very high on pallets and could potentially fall during an earthquake, select PMF 2. Select this PMF if stored to the ceiling in a pre-engineered steel building (Butler-type building), where shifting of pallets could push the wall.

3 For other conditions that the reviewer believes could inhibit tank function following an earthquake, assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Rapid Visual Screening Score Sheet | TK-05

Unanchored Vertical Tanks

ID Number ______________________________

Comments______________________________

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Tank Category (circle one)

Diameter	Aspect Ratio					
	H/D ≤ 0.5	0.5 < H/D ≤ 0.8	0.8 < H/D ≤ 1.1	1.1 < H/D ≤ 1.4	1.4 < H/D ≤ 1.8	H/D ≥ 1.8
D≤ 10'	I	I	I	I	I	I
10' < D ≤ 15'	I	I	I	II	III	IV
15' < D ≤ 20'	I	I	III	IV	IV	V
20' < D ≤ 25'	I	III	IV	IV	V	V
25' < D ≤ 30'	I	III	IV	V	VI	VI
30' < D ≤ 35'	II	IV	V	V	VI	VI
D ≥ 35'	III	V	V	VI	VI	VI

Demand Matrix (circle one)

Seismic Zone	Tank Category					
	I	II	III	IV	V	VI
1	A	A	B	C	D	F
2	A	B	C	D	E	F
3	B	B	C	D	E	F
4	B	C	D	E	E	F

Scores and Modifiers - Vertical Tanks

(circle a Basic Score and all PMFs that apply - use the column indicated by the Demand Matrix above)

	Description	A	B	C	D	E	F
Basic Score		**6.5**	**5.5**	**4.5**	**3.5**	**2**	**2.0**
P	1. Riveted shell seams	2.1	2	1.3	0.5	0	0.0
M	2. Rigid pipe attachments	3.6	2.6	1.6	2	2	2.0
F	3. Shell thickness unknown	1	1	1	1	2	2.0
	4. Other________________						
Final Score = Basic Score - **largest applicable** PMF							

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Page 1 of 2

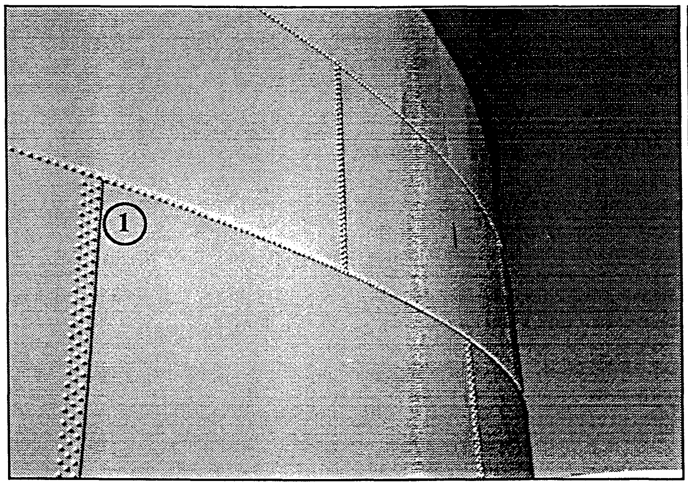
Tank Category Explanation

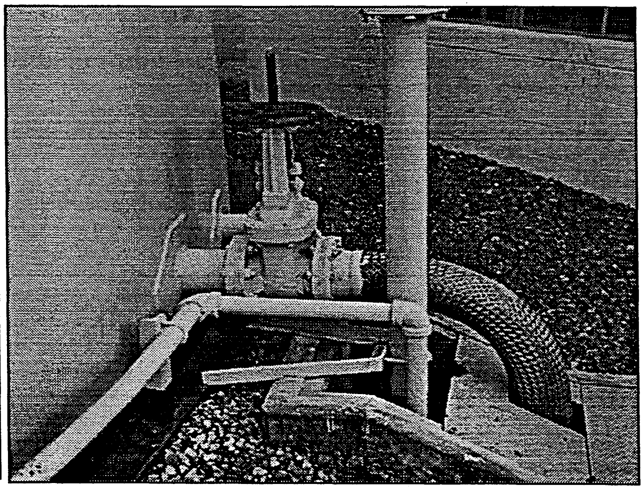
Determine the diameter (D) of the tank and the height (H) of the liquid in the tank. If the tank is normally two-thirds full, use two-thirds of the tank height for the liquid height. The aspect ratio is the liquid height (H) divided by the diameter (D). Use these values to select the Tank Category for the tank. The Tank Category will be a Roman Numeral from I to VI that will indicate which column from the Demand Matrix to select the Demand Level. If the tank category is V, choose the Demand Level from Column V on the Demand Matrix. Circle the Demand Level in that column corresponding to your Seismic Zone.

Note: If the tank is located on top of a building or in the upper 1/3 of a building's height, increase the Demand Level by one letter, up to the maximum level of F.

Performance Modification Factors (PMFs)

1. Tanks with riveted seams are susceptible to tearing of the seams under seismic loads. If the tank has riveted seams select PMF 1.
2. Certain pipe connections to tanks are likely to fail in an earthquake. If the pipe exiting the tank does not have adequate flexibility because it runs directly underground, has a rigid support or restraint within a few feet of the tank, or does not appear to be able to sustain several inches of displacement, select PMF 2. The pipe in the picture below has had flexible piping installed because it was too rigid.
3. If the tank shell thickness is unknown or known to be less than about 1/2" for tanks with Demand Level "F" the tank will require more detailed analysis. Select PMF 3 which will give the final score of 0.0. Also select this PMF if the tank is made of stainless steel (likely to be thin walled) or other materials such as fiber reinforced plastic (Fiberglass).
4. For other conditions that the reviewer believes could cause the tank to release its contents following an earthquake (e.g. a history of problems with this tank), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF.

Part B

Supporting Documentation

1. Introduction
2. Overview of Assessment Method
3. Identification of Critical Equipment and Systems
4. Derivation of Component Scores
5. Component Fragilities
6. Derivation of System Scores
7. Risk Management
8. References

Appendix A: Literature Search: Performance of Non-structural Components During the Northridge Earthquake

Appendix B: Literature Search: Damage from Earthquakes Occurring Between 1987-1991

Appendix C: Parameters for Fragility Functions Used to Derive Basic Scores and PMFs

PART B: SUPPORTING DOCUMENTATION
DETAILED TABLE OF CONTENTS

DETAILED TABLE OF CONTENTS
(Cont'd)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

INTRODUCTION

This section describes the objectives and scope of work of this study, and the organization of this report. This study is part of a multi-year program aimed toward assessing and reducing earthquake risk for critical facility equipment systems. The overall program has several phases, including: (i) collect data on the layout, use, and past seismic performance of equipment systems, (ii) develop a simplified methodology to assess equipment fragility and system reliability, and (iii) disseminate the methodology in a format that can be used by code-writing bodies, emergency-response facility owners, and operators of valuable facilities. This report represents the supporting technical documentation for the second phase of the program: development of an assessment methodology.

1.1 Background

While improving the structural safety of buildings in earthquakes has received considerable attention in recent years, less effort has been directed at improving the performance of critical equipment systems during and after earthquakes.

Monetary losses in earthquakes due to non-structural damage can be much larger than the losses due to structural damage. The ability of a facility to function after an earthquake is as dependent on the functionality of its critical systems (e.g., power and water) as it is on the stability of the structure itself. The need for a program to effectively assess and improve the seismic reliability of a building's critical systems is apparent.

For example, the 1994 Northridge earthquake caused considerable damage and service disruption to critical facilities, especially hospitals and other health service operations, including the Olive View Medical Center, the Holy Cross Medical Center, and the Indian Hills Medical Center, all in Sylmar; the Granada Hills Community Hospital; and the Veterans Administration Medical Center in Sepulveda.

Service disruptions at all of these facilities were attributed primarily to non-structural or equipment failures, including fire protection piping, HVAC, power distribution, and control system problems. Failures were reported in diverse equipment systems such as emergency power generation, hospital communications, and the medical gas system.

The performance of essential facilities in the Northridge earthquake is especially notable because current building code requirements for hospitals in California attempt to maintain functionality of the facility, as well as preserve the life-safety of the occupants. The area of Southern California surrounding the Northridge Earthquake was fortunate to have an extensive health care network that could respond to the demands of a large, natural disaster even with the loss of multiple facilities. The consequences of similar, post-earthquake facility performance in other earthquake prone regions of the United States might be devastating; especially if a major event occurs in an area with less overall earthquake preparedness than Southern California.

The inability of these critical facilities to function following a strong-motion earthquake points to deficiencies in the design approach recommended in current standards, at least when functionality is one of the performance goals. Because of the focus on providing structural integrity (primarily through anchorage design) for a given component, other vulnerabilities that can inhibit functionality are overlooked. Differential displacement of system components and interactions with structural items are just two examples of non-anchorage related concerns that can inhibit functionality.

Additionally, existing facilities tend to have vulnerabilities that are not addressed in design standards. For example, system repairs and modifications that have not gone through a rigorous seismic design process can unintentionally add to the overall system seismic risk. The *ad hoc* nature of many of these repairs or modifications makes them difficult to address in a design standard.

1.2 Project Description

This report documents part of a multi-year program aimed toward reducing earthquake risk for critical facility equipment systems and components. The program goals are to determine which equipment components are critical to life safety and normal operations, document their performance in past earthquakes, and utilize these data to develop a method to assess existing facilities and cost-effectively reduce seismic risk through selected strengthening or systems modifications.

Part C of this document addresses dissemination of data in model code provisions such that code-writing bodies can implement the results of this study for incorporation into new design requirements.

The first phase of the project focused on compiling data on the function and seismic reliability of major components critical for life safety and normal operations. Four important facility types were reviewed:

- High-rise office buildings
- Telephone central offices
- Data processing centers
- Hospitals

Sample sites of each facility type were visited. At each facility, operations managers and personnel were interviewed and equipment was reviewed. Equipment components in systems critical to operation were identified, along with system dependencies and backups, should a given equipment component fail in an earthquake.

Generalizations regarding equipment vulnerabilities were developed by examining in detail the historic seismic performance of six key equipment systems:

- Uninterruptible power supply (UPS)
- Standby and emergency power generation
- Fire detection
- Fire suppression
- Air conditioning
- Power distribution

Investigations from past earthquakes were used to identify seismic vulnerabilities of specific types of equipment in these systems. Reviews of these investigations focused on damage that has caused components to fail to perform their intended service (functional failure), as opposed to damage that had no effect on component function (e.g., dents, minor overstresses, etc.).

The results of that phase of the project have been documented in a report (NCEER-93-0022) and used in subsequent phases of the project.

1.3 Objectives of Handbook and Supporting Documentation

The phase of the program documented in Parts A and B addresses the overall project goal of developing a methodology for assessment of equipment system seismic reliability for use in risk management. As part of that effort a handbook has been developed which describes a methodology to assign relative grades to equipment components and systems. That method will help to identify "weak links" and assess potential risk mitigation options.

This report provides supporting technical documentation for the handbook. It describes the bases for the scoring system used in the evaluations. The scoring system is the key element in an overall program that is intended to be used by engineers, building officials, owners, and other individuals interested in assessing and improving the functional reliability of equipment systems.

1.4 Screening Methodology

The screening methodology presented in this document was envisioned as a natural progression of the process developed as part of *ATC-21, Rapid Visual Screening of Buildings for Potential Seismic Hazards*. That program was developed to provide a systematic way for non-technical people to efficiently assess the relative seismic risk present in a group of buildings. Intended as a starting point for more detailed future assessments, *ATC-21* presented a rigorous, simple system that could be applied to almost any situation.

Another program developed for screening mechanical and electrical systems and components was created by the Seismic Qualification Utilities Group (SQUG) for use in nuclear power plants. The group was organized by most of the large electrical utilities in the United States that operate nuclear power plants to address concerns raised by the Nuclear Regulatory Commission (NRC) regarding safety at nuclear plants designed to older seismic standards. The SQUG approach made use of experience gained from past earthquakes in predicting the effects of future events. While this eliminated many of the detailed analyses and shake table tests that were previously used to determine seismic vulnerability of equipment, the method also depended on highly trained personnel going through a rigorous proceduralized process to satisfy evaluation requirements as prescribed by regulators.

The program presented here also makes use of information obtained from major earthquakes, but in a more simplified manner than utilized in the nuclear industry, to allow implementation by a wider range of personnel. Because of its general nature and its intent to provide results in a relatively short period of time, the results of screening evaluations using this methodology should not be used as the sole determination for decisions on system modification. Rather, they should be considered as an element in an overall risk management program that is key to helping owners understand the relative importance of individual components and to identify those areas most likely to benefit from more detailed reviews or potential modifications.

1.5 Organization of Part B

This document is intended to provide additional background technical documentation to support the Handbook in Part A. This document is organized as follows:

- Section 2 discusses a detailed methodology for identifying critical systems and components and the development of systems diagrams.
- Section 3 describes the scoring system and the mechanics of applying it to a specific equipment system.
- Section 4 describes the derivation of component scores for use in the scoring system.
- Section 5 contains examples of the methods used to determine fragilities for various system components. Various methods for calculating fragilities are described, as well as limitations of "generic" application to existing systems.
- Section 6 contains details description of the derivation of the scoring system, including special consideration for considering redundant components.
- Section 7 discusses risk management.
- Section 8 lists references.
- Appendix A presents an example of raw data from a literature search on performance of non-structural components in the Northridge earthquake.

- Appendix B presents a literature search of damage from earthquakes occurring 1987-1991.
- Appendix C presents parameters for fragility functions used to derive basic scores and PMFs used in the scoring method.

SECTION 2

OVERVIEW OF ASSESSMENT METHOD

This section of the supporting documentation summarizes the overall evaluation process and the mechanics of the screening process, including the scoring system and a description of how results are intended to be interpreted.

2.1 Screening Methodology

The screening methodology is a process by which critical systems and components are identified and assessed, and scores are assigned to each component and system. A higher score indicates higher reliability.

The screening methodology uses the following general procedure:

1. Identify which systems are required to remain functional during and/or after an earthquake. These systems may be necessary for life-safety purposes (e.g., fire protection) or for the facility to remain operable (e.g., power, HVAC).

2. For each system selected, identify major electrical and mechanical components, as well as support functions (water, power, HVAC) and distribution systems (piping, ducts). These equipment items are usually considered to be major items, such as pumps, transformers, distribution panels, etc. However, smaller items or subcomponents, such as a relay for a fuel transfer pump, might be specifically identified because of their importance to the operation of the overall system and a particular concern about their vulnerability.

3. Graphically sketch the system processes, identifying critical components, system dependencies, and redundancies. This systems evaluation should consider operator actions which are required to continue operation or to mitigate potentially dangerous situations (e.g., turning off gas valves or resetting relays). The process is similar to creating a "failure tree" or "event tree". An example is shown in Figure 5-1 in Part A of this document.

4. Perform a screening inspection of each of the components in the systems, using the evaluation checklists found in the handbook. Assign scores for each component according to the particular vulnerabilities present in that component, the location in the building and site hazard, the historical performance of that equipment item, and other factors.

5. Combine scores of individual components for each system to determine an overall score for that system. A higher score indicates higher reliability.

6. Evaluate scores for individual components to identify "weak links" in individual components that affect functionality of the component. Use the scoring method

to identify all vulnerabilities that may require some mitigation or further evaluation.

7. Use the results of the steps above to make risk management decisions. This may also include cost-benefit analyses to evaluate different options and additional evaluations to confirm screening evaluation findings.

2.2 Assigning Scores to Components

The scoring methodology for an individual component uses the following logic:

1. Each component is assigned a basic score that is a function of the performance history of that type of equipment, and the seismicity of the site. Those scores have been developed for broad categories of major equipment components. The derivation of these basic scores is described in detail in Section 4.

2. The basic scores are modified by Performance Modification Factors (PMFs) which indicate the decrease in reliability due to specific configurations or details that may be present in an equipment installation. Each detail that might affect the seismic vulnerability is assigned a PMF consistent with its relative effect on functionality, as described later.

3. The evaluation and checklist are completed such that the basic score and all applicable PMFs are identified.

4. The equipment item is assigned a score equal to its basic score minus the largest (worst case) applicable PMF. If further evaluations or system modifications lead to the determination that a particular PMF is no longer relevant, the second most critical PMF is then used.

2.3 Combining Component Scores to Determine System Score

The scoring methodology for an entire system uses the following logic, as illustrated in the simplified representative system diagram of Figure 5-1 in Part A:

1. Where a group of multiple components are all needed for a particular function (indicated by an "and" gate), the lowest score of the individual components is used as the net score for that combination of components.

2. Where there is redundancy (indicated by an "or" gate), the user is given the option of using the highest value, or calculating a "composite" score using a formula which considers the highest value and the total number of redundant components. Further discussion on this formulation is provided in Section 5.

2.4 Consideration of Site Seismicity

The basic scores have been developed considering the level of seismic hazard for the region of the nation in which the facility is located. This is done by assigning different scores for different levels of seismic hazard, derived here using the levels of seismic acceleration specified in the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings* and the *Uniform Building Code.*

As discussed in Section 4, scores were derived by convolving vulnerability data in the form of fragility functions with seismicity data in the form of a seismic hazard curve. The resulting score is a measure of relative probability of failure. The reader is cautioned that the results are not intended to provide a rigorous estimate of probability of failure of a system.

2.5 Use of Scores

The purpose of the scoring system must be understood in the context of the overall program. It is intended for use as a rapid screening evaluation procedure by individuals who may not have specialized training or experience in seismic engineering, and is not intended to replace detailed engineering evaluations. It is also not intended to give a mathematically rigorous, quantitative assessment of the system seismic reliability or probability of failure. It must be recognized that as a screening process, it is possible that seismically weak aspects of a system may be ignored entirely and the importance of certain equipment items may be overestimated or underestimated. However, when applied to an entire system or facility, the scoring method can identify where detailed investigation of a specific component, or system modifications may have the most significant benefits in terms of system reliability.

After completing the scoring for all of the systems in a facility, the user can review individual scores and determine which systems, sub-systems, and components are the primary causes of low overall scores. A review of the checklist for a component will help to quickly identify the causes of low scores for that component, whether from the generic performance history of the equipment type (as shown in the basic score) or from a specific vulnerability or concern identified during the checklist review (as shown in the PMF).

The impact of various mitigation options may also be assessed by simply recalculating scores with the potential modification or component scoring change. It will become apparent where repairs or modifications will increase the score and which vulnerabilities need to be addressed to have the largest impact. It will also become apparent where systems modifications, such as adding redundant components, may be more beneficial to increasing reliability than strengthening an individual component.

The following examples illustrate the thought process used to interpret the results of the checklist evaluation and scoring process:

- When the score of one component in a system is much lower than other component scores and seems to control the system score, that component may be evaluated in more detail using other methods.

- If more detailed evaluations show that the individual component identified above should be assigned a higher score, the system scores can be recalculated and reevaluated. For example, a drawing might be located that identifies anchorage that cannot be seen and was previously assumed not to exist, or a calculation might show that the capacity of a connection is much higher than judged by the person performing the screening review.

- Similarly, if a detailed evaluation of an individual component indicates that a significantly higher score can be achieved by performing an inexpensive modification, an owner may consider performing that modification. Scores should then be recalculated, recognizing the revised condition of the equipment. For example, removing an impact hazard such as a bookshelf adjacent to a control panel may be all that is necessary to significantly increase the scores of the component and the system.

- If the score for a component is low because the particular equipment type has low basic scores (e.g., due to poor seismic performance history) or because of many vulnerabilities that are difficult to alleviate, further evaluation or modification to the component may not significantly impact the system reliability and may have little or no benefit at a substantial cost. In such circumstances, systems modifications, such as adding redundancy, may be considered.

KEY		
SYMBOL	NAME	MEANING
	AND GATE	Component above gate functions if all components below function
	OR GATE	Component above gate functions if any component below functions

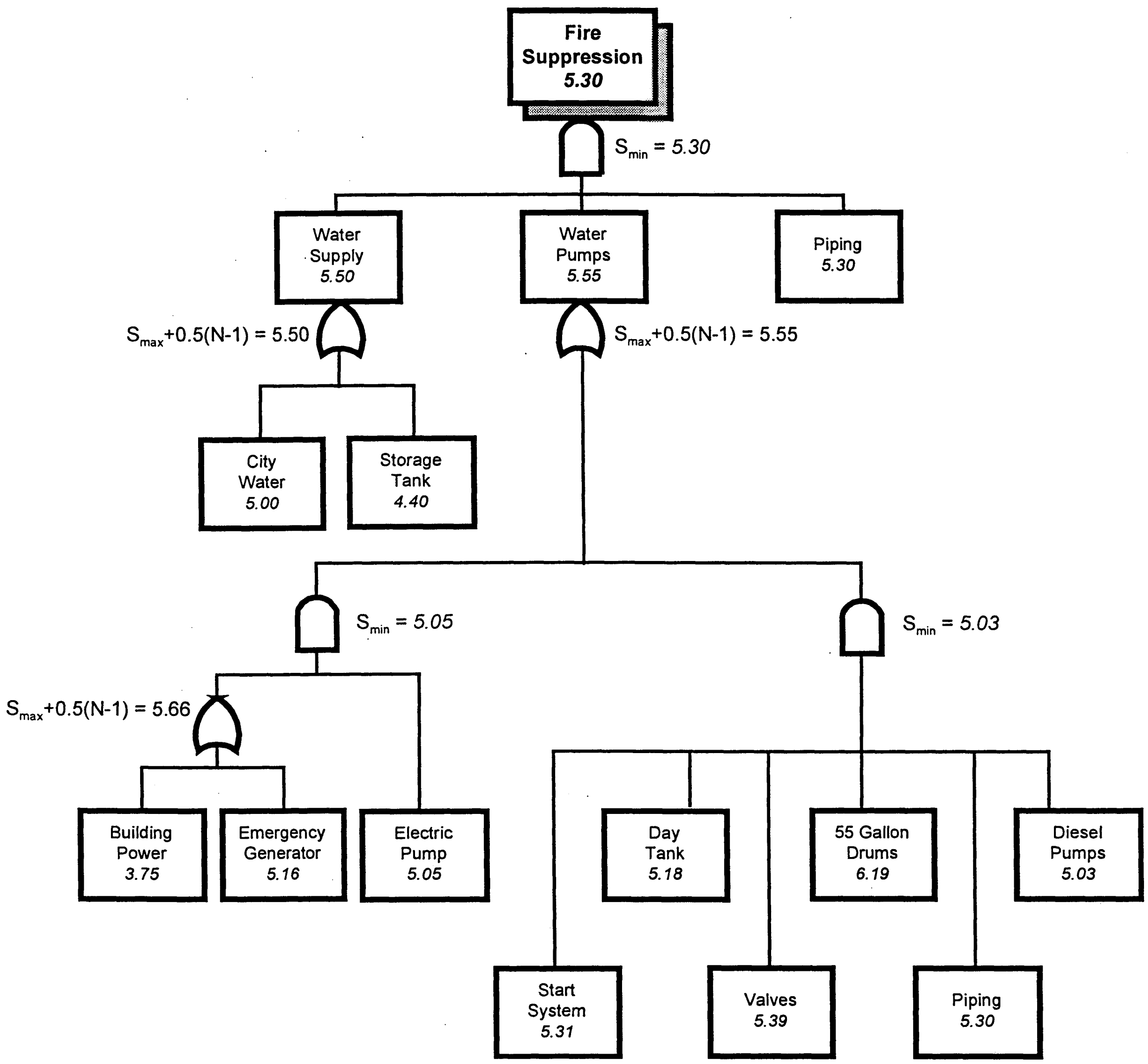


Figure 2-1: Example of scoring mechanics. Numbers shown here been selected for illustrative purposes only.

SECTION 3

IDENTIFICATION OF CRITICAL EQUIPMENT AND SYSTEMS

Section 2 provided discussion of the overall process. This section of the supporting documentation deals with the process of component and system identification. This should be reviewed in conjunction with Section 2 of the Handbook.

3.1 Purpose

Most evaluations of existing facilities use methods consistent with those used for new design and may use the same criteria. Risk is addressed *a priori*, using appropriate industry criteria. Assessments are carried out by different disciplines (e.g., mechanical, structural) using different techniques and to inconsistent levels of safety or reliability.

The use of broad design criteria may be effective in some applications, but it can lead to evaluations that are overly conservative in some areas or that fail to provide the desired degree of reliability in other cases.

One of the primary purposes in developing this evaluation process was to incorporate risk exposure concepts into the evaluation process in a manner which is technically appropriate, yet straightforward and practical for use by personnel who are not highly specialized in the area of risk analysis.

To that end, the systems assessment process described in Section 2 of the handbook was developed, with an associated "scoring system" for prioritizing and ranking concerns. This chapter provides additional background information to supplement Section 2 of the handbook.

3.2 Approach

It was recognized that in order to address the concerns described above, the various sources of risk must be tied together in a logical and consistent format. To serve that purpose, a fault tree/event tree type of methodology was incorporated.

Fault tree analysis is a powerful tool for analyzing system failures in complex systems. It uses top-down logic to model the significant causes and combinations of causes that would allow an undesired "top" event to occur.

This approach is commonly used in detailed quantitative risk analyses (QRAs), where event consequences and frequencies are determined using detailed engineering calculations and estimates. The method is accepted within the process industries for hazard evaluation by OSHA regulations on process safety management, 29 CFR 1910.119.

The costs of conducting explicit QRAs can be substantial. For our application, a variation of this approach is used to simplify the analysis and still capture the overall risk and reliability levels. Where fault trees identify causes and combinations of causes of failure, our logic diagrams identify causes and combinations of causes that will result in successful operation of our system and facility.

The major steps involved are described in more detail in the Handbook and in the following sections.

3.3 Identification of Critical Systems and Components

Section 3 of the Handbook describes in detail the procedure for identifying facility and system functionality requirements, and critical systems and components. That process is documented using a series of checklists made up for typical systems and components.

Guidance is also provided for dealing with other considerations, such as operator intervention requirements and accessibility, historical reliability problems, and support systems that deal with multiple systems.

3.4 Development of Logic Diagrams

Critical system diagrams serve to provide a pictorial view of the system interrelationships and provide a framework for quantifying the relative reliability of the systems following an earthquake. The critical system diagrams are a type of logic tree which uses "AND" and "OR" logic to express the system interrelationships to the overall successful functioning of the building being examined. These logic trees are then evaluated as discussed briefly in Section 2 and covered in detail in Section 6.

The Handbook provides detailed discussion on the development of logic diagrams. It should be noted that there are multiple ways of grouping systems and functions that result in equivalent definitions of system interrelationships.

3.5 Using the Results

The results of the system identification process are used in assigning scores for systems, as described in detail in Section 6 of this document and Section 5 of the Handbook. The systems logic diagrams are most useful for risk management purposes. That is discussed in more detail in Section 7 of this document and Section 6 of the Handbook.

3.6 Evaluation Personnel

The evaluation process is intended for use by personnel without specialized training in earthquake engineering. It should be noted that many of the skills used in performing evaluations described in the remainder of this document and this process would be familiar to structural and mechanical engineers practicing in earthquake regions. However, the skills used in performing the tasks described in this Section, and in Section 3 of the Handbook, would be more familiar to a systems engineer.

One of the focuses of the research program was to utilize skills and approaches from different disciplines to develop a comprehensive process for performing cost-effective evaluations. It is recognized that one person may not be able to perform the entire process, but should be able to understand the intent of each step such that required information can be appropriately obtained.

SECTION 4

DERIVATION OF COMPONENT SCORES

This section describes in detail the derivation of values used for basic scores and performance modification factors (PMFs) for various equipment categories. Derivation of values for specific equipment types is discussed in Section 5.

Two important factors are used in calculating basic scores and PMFs for each broad category of equipment. The first is a measure of the equipment vulnerability, which utilizes a fragility function as defined in this section. The second is a measure of site seismicity, as described on a regional basis by a hazard curve.

4.1 General Format of Component Scores

The component scoring system has been developed so that a score is assigned as a measure of the relative reliability of that component functioning following an earthquake. A higher score indicates higher reliability. Data sheets in the form of checklists have been developed for many different types of electrical and mechanical equipment which would be expected to be major components in critical equipment systems. Figure 4-1 in the Handbook in Part A shows an example of one such data sheet, for emergency batteries. The major elements of the component scoring system are illustrated on the sheet of Figure 4-1 of Part A and described in the following paragraphs.

4.1.1 Earthquake Load Level

Different scores are provided for equipment which is expected to be subjected to different load levels due to earthquakes. The different load levels, or seismic demand, could be due to local seismicity as well as location in the building. Basic scores and PMFs were determined for five different load levels. A matrix is used to determine what load level is appropriate for the location of the particular item being evaluated.

The most easily understood and useful representation of site seismicity is provided by the seismic zonation coefficients of common building codes. Two such codes commonly referenced are the *Uniform Building Code* (UBC) and the model code provisions of the National Earthquake Hazards Reduction Program (NEHRP). The UBC is the code adopted for use by the State of California, and has to date been the most well known code used for seismic design in the United States. The NEHRP provisions have been adopted by various national codes, such as the Standard Building Code and National Building Code. It is expected that the seismic design provisions of the International Building Code, which is expected to be the common code for the entire United States, will resemble the NEHRP provisions more than the UBC.

The UBC currently represents the United States in 4 zones, with effective peak accelerations (EPAs) ranging from 0.1 to 0.4g. The NEHRP provisions represent the United States in 7 zones, ranging from 0.05g to 0.4g for the term A_a, which is analogous to the "Z" factor used to denote the EPA in the UBC. Both model codes correlate the acceleration values to a 10 % probability of exceedance in 50 years. An evaluator of a facility must determine the seismic zone for the facility one time and use that zonation throughout the entire process.

Besides the location of a facility, the location of an equipment item within a building also affects the seismic load experienced by the equipment. The NEHRP provisions identify a linear amplification of loading from the base of the structure to the roof, regardless of building height. The load at roof level is from two to four times the acceleration at the base, depending on flexibility of the equipment and other factors. Analysis of earthquake records taken at the base and roof of buildings in the 1994 Northridge, California earthquake also support an average amplification of peak acceleration of between two and three.

For this scoring method, a matrix is provided to combine the effects of site location (seismic zone) and location within a building. As illustrated in Figure 4-1, the user looks up the appropriate earthquake load level classification, for which specific basic scores and PMFs are provided in a table.

It is recognized that several effects are ignored in this simplified process, such as frequency content of amplified motion within a building and site-specific hazards at locations within a seismic zone. The parameters used to define the seismic load classification were selected because they are readily available without performing analysis and are commonly used by building officials and others not trained in seismic design. Furthermore, they provide a simple means of defining load with reasonable accuracy within the bounds of the analytical models used in developing this screening tool.

4.1.2 *Basic Scores and PMFs*

Values of Basic Score and PMFs for each load level classification are located on the scoresheet, such as shown in Figure 4-1 in Part A. The user is instructed to circle the basic score and all PMFs that apply to that equipment. It is important that the user perform a complete evaluation and identify all applicable PMFs, as even PMFs that do not affect the component score may affect upgrade decisions when using these sheets to assist in risk management decisions. For example, if two applicable PMFs are identified of equal or similar value, an owner should recognize that they must perform modifications or further analysis to reduce or eliminate both applicable PMFs in order to increase the total component score.

4.1.3 *Total Component Scores*

Total scores for each component are calculated by subtracting the worst case (largest) PMF from the basic score. Although it is recognized that using only the worst case, and ignoring other PMFs in computing the total score, slightly overestimates the reliability of an equipment item with multiple applicable PMFs. However, the additional complexity that would be required in a scoring system to account accurately for all applicable PMFs cannot be justified in the overall context of uncertainty in the PMF values and the intended use of the process as a screening tool.

4.2 Basis of Component Scores

Component scores have been developed for "generic" conditions by considering equipment fragilities and seismic hazards as described below. Additional discussion on equipment fragilities is provided in Section 5.

4.2.1 Equipment Fragilities

The seismic fragility of a structure or equipment item is the conditional probability of reaching a limit state under a given level of seismic loading. For the purpose of this project, the limit state is defined as the failure of the component to perform its intended function (functional failure). The seismic loading is defined in terms of acceleration, such as peak ground acceleration (PGA) for a site, zero period acceleration (ZPA) for a particular equipment item located at a site, or spectral acceleration (S_a).

The objective of the fragility evaluation is to estimate the capacity of a given component relative to a ground acceleration parameter such as PGA or spectral acceleration. The "capacity" can be represented by a family of fragility curves, as shown in Figure 4-1. Each curve represents a confidence level, i.e., for the 95% confidence level, the analyst has 95% confidence that the "true" fragility lies to the right of (higher than) the curve shown. The mean fragility is the average of all possible curves.

Figure 4-2 shows a probability density function and a cumulative distribution function for the capacity of a component expressed in terms of acceleration "a" (e.g., PGA, S_a). The total area under the density function is unity and the shape of the function represents the distribution of likely true capacities for the component in terms of "a". The cumulative distribution at acceleration "a" is the area under the curve between 0 and "a" and represents the probability that the capacity is less than or equal to "a." Therefore, the cumulative distribution function is equal to the probability of failure at each value of "a", and is in fact the fragility curve for that component.

4.2.2 Lognormal Formulation

There are two types of variabilities considered in the fragility evaluation. The S-shaped curve indicates randomness in the response of an item to an earthquake because of variability in the ground motion (e.g., duration, frequency content, etc.). This variability cannot be practically reduced within the bounds of the analytical model.

The median capacity of a component is also considered to be variable, as indicated by the family of fragility curves in Figure 4-1. That variability is referred to as the uncertainty, and is generally considered to be due to lack of knowledge that could be reduced by further testing or detailed studies. Examples of uncertainty include actual material strengths and other properties, or actual capacities of connection details installed by an equipment vendor.

These variabilities are incorporated into the fragility model used in this project by using a lognormal model, with the entire family of fragilities for a component corresponding to a particular failure mode expressed in terms of the best estimate of the median acceleration capacity, A_m, and two random variables. Thus, the acceleration capacity, A, is given by:

$$A = A_m \, \varepsilon_R \, \varepsilon_U \quad (4\text{-}1)$$

in which ε_R and ε_U are random variables with unit medians, representing, respectively, the inherent randomness about the median and the uncertainty in the median value. In this model, we assume that both ε_R and ε_U are lognormally distributed with logarithmic standard deviations, β_R and β_U, respectively.

If knowledge of the system were perfect one would only account for the random variability, β_R. Then the conditional probability of failure, f_O, for a given acceleration level, a, is given by:

$$f_O = \Phi\left[\frac{\ln(a/A_m)}{\beta_R}\right] \quad (4\text{-}2)$$

where Φ is the standard Gaussian cumulative distribution function. The relationship between f_O and a is the median fragility curve with a median acceleration capacity of A_m.

Of course, perfect knowledge of a system is unattainable and some amount of uncertainty exists. Including this uncertainty, β_U, makes the fragility a random variable. Thus, at each acceleration value, the fragility, f, can be represented by a subjective probability density function. Q is the subjective probability, or confidence, that the conditional probability of failure, f, is less than f′ for a given peak ground acceleration. The relationship between Q and f′ is described by the following equation:

$$f' = \Phi\left[\frac{\ln(a/A_m) + \beta_U \Phi^{-1}(Q)}{\beta_R}\right] \quad (4\text{-}3)$$

The variables A_m, β_R and β_U determine a family of fragility curves, representing various levels of confidence, as shown in Figure 4-2.

A mean fragility curve can also be calculated, which is the weighted average of all possible curves. An important short cut is available to calculate the mean curve without averaging all individual curves. The mean curve is also a lognormal function of the median capacity and a combined uncertainty β_c, where

$$\beta_C = \sqrt{\beta_R^{\,2} + \beta_U^{\,2}} \quad (4\text{-}4)$$

As can be seen in Figure 4-1, the mean curve is more spread out than the median curve because the median curve has a smaller logarithmic standard deviation. Only the mean curves are used in formulation of component scores.

4.2.3 *Measures of Acceleration*

All fragility estimates in this project are referenced to the peak acceleration, i.e., either the peak ground acceleration (PGA) or zero period acceleration (ZPA). Although there are other measures of earthquake motion or intensity that may be better indicators of likely damage, the PGA and ZPA were selected for several practical reasons, including the following:

i. Earthquake performance data typically reference the site PGA.

ii. Site or regional seismicity in most building codes is defined in terms of PGA; therefore code-specified values of PGA (or similar equivalent terms, such as effective peak acceleration (EPA)) are available for any location in the United States.

iii. Many major equipment items are rigidly anchored to the floor and will respond to the peak ground acceleration or in-structure acceleration (the ZPA).

iv. An equipment item ZPA can be estimated from the site PGA and location in the building or support structure. For equipment located at ground level, the ZPA and PGA are equivalent.

4.2.4 *HCLPF*

Of particular interest to this project is the point on the 95% confidence curve that corresponds to a 5% probability of failure. This point is commonly referred to as the High Confidence of a Low Probability of Failure (HCLPF) value. This acceleration is defined as:

$$HCLPF = Am * e^{-1.65(\beta_R+\beta_U)} \qquad (4\text{-}5)$$

It is common and useful to infer a physical significance to the HCLPF acceleration. For interpretation of certain failure data, the HCLPF has been defined as the "threshold" of failure, or the acceleration level at which failures begin to occur.

4.3 Methods to Estimate Component Fragilities

Fragility data were generated for various types of major equipment components that are typically part of key systems in critical facilities. Various methods were used for generating fragilities, such as:

- Documented detailed earthquake experience data, including both successes and failures.
- Documented detailed earthquake experience data without failures included.
- Extrapolation of detailed data from similar components expected to contain similar vulnerabilities.

- Limited data on earthquake and testing performance.
- Statistics on calculations of capacities and uncertainties used in risk calculations for similar components at older nuclear power plants.
- Judgment of engineers intimately familiar with equipment vulnerabilities.

Discussions of each of the methods and examples of their applications are presented in Section 5.

It must be noted that for the purposes of *screening*, as used in this methodology, the relative fragility is most important, rather than the absolute fragility, as the intent is not to calculate an actual probability of failure. This is especially important to remember when comparing fragilities calculated using different methods. Also, some basic scores are determined based on fragility data for equipment with "ideal" installation, while basic scores for other components are determined from fragility data for "standard" installations. Assessments were made to identify and correct inconsistencies in capacities and uncertainties.

4.4 Generating Basic Scores from Fragilities

Basic Scores were calculated as the negative of the logarithm (base 10) of the annual probability of failure.

$$\text{Basic Score} = -\log_{10}(P_{fa}) \qquad (4\text{-}6)$$

The annual probability of failure is calculated by convolving the fragility curve of a component with the seismic hazard curve. The convolution is described by the following equation:

$$P_{fa} = \int_0^{\infty} \frac{-dH(a)}{da} P_{fc}(a)\,da \qquad (4\text{-}7)$$

where P_{fa} is the annual probability of failure and P_{fc} is the conditional probability of failure. H(a) is the hazard curve.

4.4.1 Definition of Seismic Hazard

To apply this methodology to a wide range of locations, a "generic" seismic hazard curve is required. The Department of Energy has identified "representative" probabilistic seismic hazard curves in draft versions of Standard 1020, which are shown in Figure 4-3 for a "high" seismicity and "low" seismicity site. It is recognized that actual site-specific curves may differ substantially from this idealized situation, but for the context of usage in this methodology, a constant slope was selected to represent the "generic" hazard.

The resultant hazard curves are shown in Figure 4-4. These curves have a constant slope, and with a value "Z" at a probability of exceedance of 0.002. This corresponds to the values defined in the *NEHRP Recommended Provisions* as the PGA with a 10% probability of exceedance in 50 years, and is a common parameter used to define a site hazard.

4.4.2 *Calculation of Scores*

The fragility curves were convolved with the hazard curves for values of EPA ranging from 0.1 to 0.4g to calculate annual probabilities of failure using Equation 4-7 above. Those values were then converted into Basic Scores by using Equation 4-6.

The convolution of a fragility curve with the seismic hazard curve corresponding to 0.1g at .002 annual probability of exceedance will result in one value of probability of failure and one value of Basic Score for 0.1g PGA (Zone 1). The calculations are repeated for other hazard curves to derive a complete set of basic scores. The results are shown in Figure 4-5.

4.4.3 *In-Structure Amplification*

Categories of equipment that are typically mounted above grade in buildings will experience building amplification. This was accounted for in the fragility formulation by identifying the typical elevations above grade of equipment that form the basis of the fragility calculation. An amplification factor was assigned from 1 (bottom 1/3) to 2 (top 1/3 of building), irrespective of building height.

The 1994 NEHRP provisions use a similar methodology for amplified response relative to the percentage of building height, but independent of total height of the building. Drake and Bachman (1996) report on the reduction of measured acceleration data from over 400 data sets from California buildings experiencing recent earthquakes, showing the normalized ratio of in-structure acceleration to ground acceleration as a function of percentage of building height. The linear regression average roof acceleration was around 2.5 times the ground acceleration. The NEHRP recommended provisions for new design use a factor of 4. For this methodology, intended for existing facilities, we have used a factor of 2 to account for amplification of equipment anywhere in the top 1/3 of the building.

The amplification factor was used in developing fragility functions, so that fragilities can be defined in terms of in-structure ZPA. The corresponding value of PGA used in the convolution calculation was based on the same set of amplification factors. Because a constant slope is used for the hazard curve, the calculations are simplified, such that an item near the top of a building in Zone 2 (0.2 PGA with an amplification factor of 2) will have the same probability of failure as an item near ground level in Zone 4 (0.4 PGA with an amplification of 1). As such, the resulting Basic Score is the same.

Using these assumptions, the Basic Scores can be grouped together for combinations of PGA and in-structure amplification that will result in similar ZPAs at the support point for a component. This is illustrated in the "Earthquake Load Level" matrix on every Rapid Visual Screening Score Sheet. Basic Scores on those score sheets have been categorized into 5 values, labeled as A to E.

4.4.4 *Amplification Due to Soft Soils*

Soil characteristics were not incorporated into the fragility formulation for sites experiencing past earthquakes. Response spectra that have been used in past model building codes, such as the Uniform Building Code, do not recognize a variation in the effective peak acceleration (EPA) with soil type, only in the shape of spectral response. However, it is well known that buildings on soft soils experience higher intensity motions and subsequent higher levels of damage to structures and contents. For this reason, it is suggested that facilities on very soft soils (e.g., Class S4 in the 1994 UBC, SF in the 1997 UBC, or Class F in the 1997 NEHRP provisions) should use a seismic load level one value more conservative than otherwise shown in the matrix. In other words, those facilities listed as D on the matrix should use the scores from column E. Those who are already listed at classification E would continue to use the "E" values.

4.5 Performance Modification Factors

Performance Modification Factors (PMFs) are assigned to various parameters and conditions that will be included on an inspection checklist for each component. These describe known vulnerabilities that tend to reduce the reliability of various types of equipment following earthquakes.

4.5.1 *PMF Methodology*

A modified score is calculated for each condition using the same formulation as described in calculation of Basic Scores, as described in Section 4.4, except with fragilities modified to reflect increased conditional probabilities of failure. The modified fragilities are convolved with the same hazard curves to calculate the modified scores.

The PMF is simply the difference between the Basic Score and the modified score for a given equipment item in a particular loading condition.

$$\text{PMF} = \text{Basic Score}(i) - \text{Score}(j) \qquad (4\text{-}8)$$

where Basic Score(i) is the basic score for the general population of components and Score(j) is the modified score for the portion of the general population of components with a given vulnerability.

4.5.2 *Modified Fragilities*

Different methods of calculating fragilities, including modified fragilities, are presented in Section 5. The particular method chosen for a given PMF for a given component includes the following:

- Calculation of capacity and uncertainty based on failure and success data.

- Estimation of modified capacity and uncertainty based on failure data only.
- Judgment of engineers familiar with equipment vulnerabilities.

For most cases, insufficient detailed data on inventories of equipment with specific vulnerabilities (e.g., unanchored cabinets) precluded the use of success and failure data to determine specific PMFs. In many of those cases, an estimate of the HCLPF capacity was used to represent the acceleration at which failures were first observed. Uncertainties were adjusted based on inventories and performance histories. From these, modified scores and PMFs were calculated.

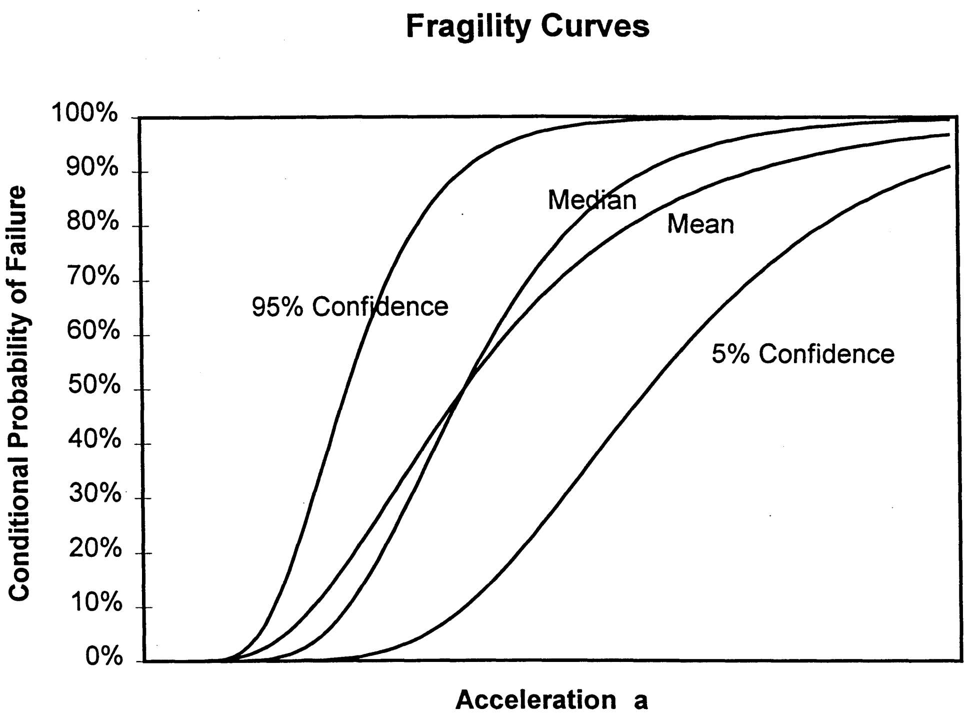


Figure 4-1: Fragility curves

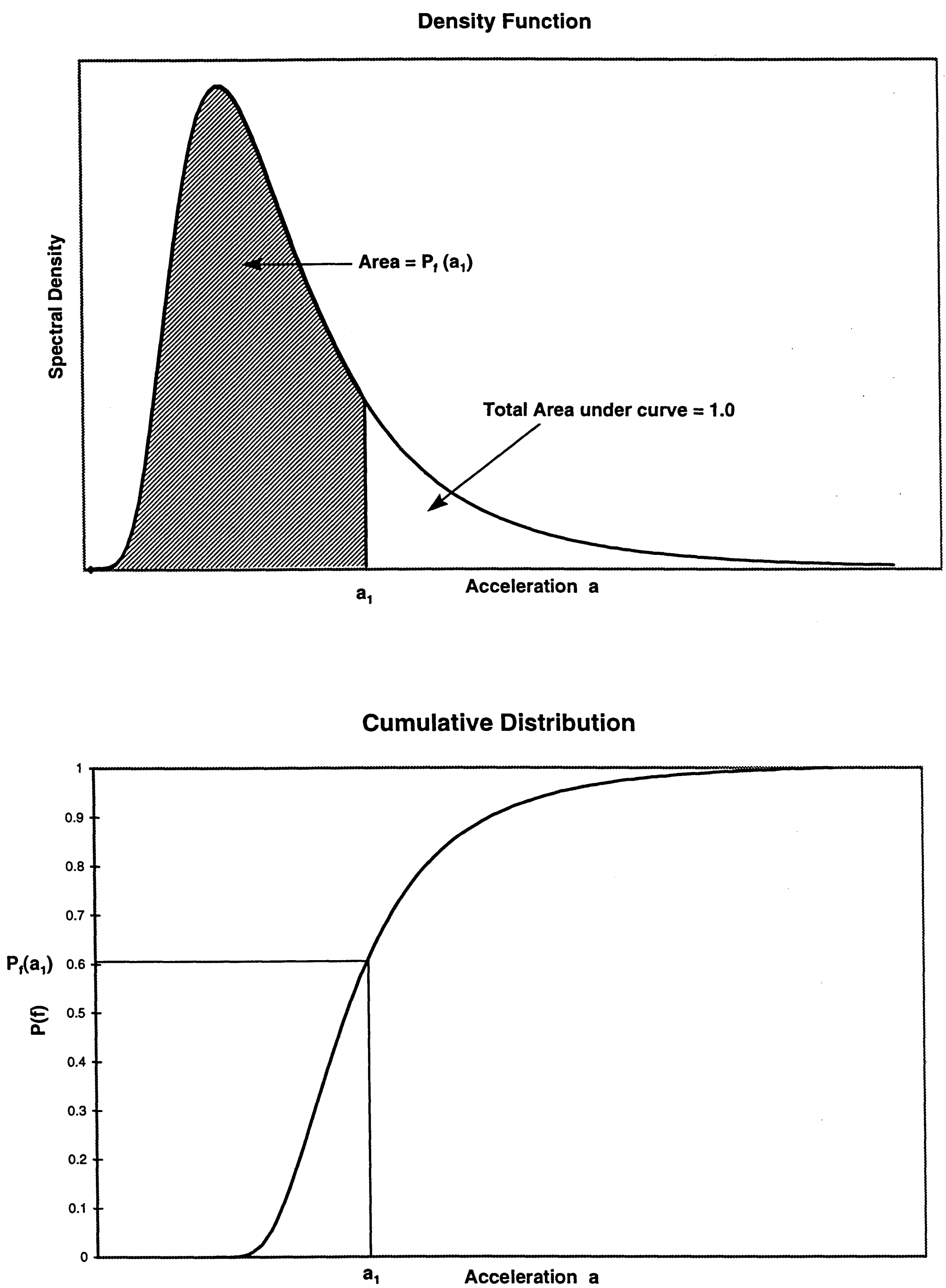


Figure 4-2: Example probability density function and corresponding cumulative distribution function (fragility curve)

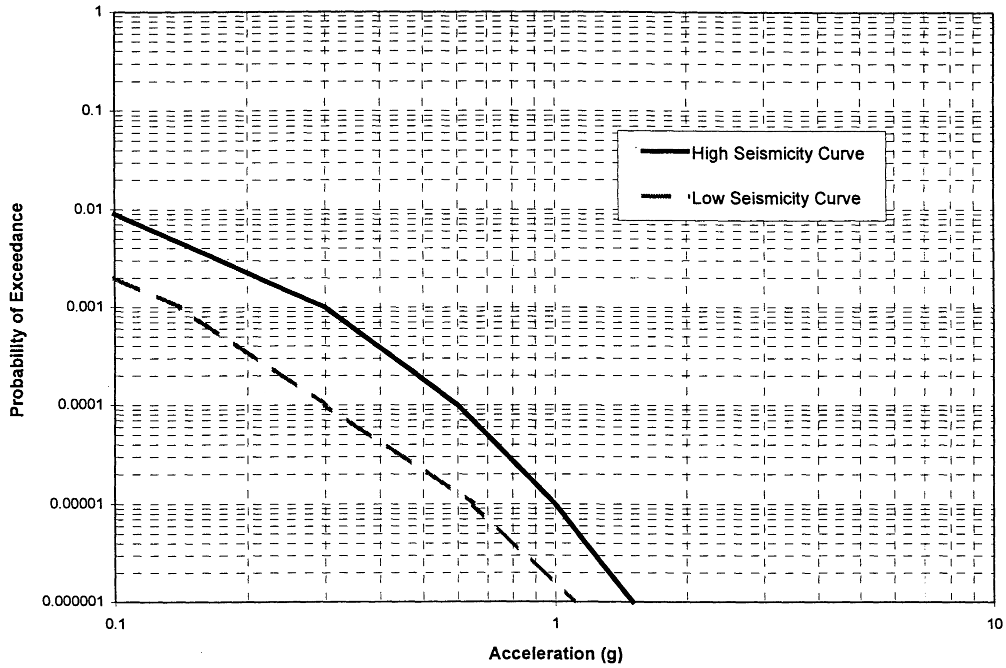


Figure 4-3: Representative probabilistic seismic hazard curves

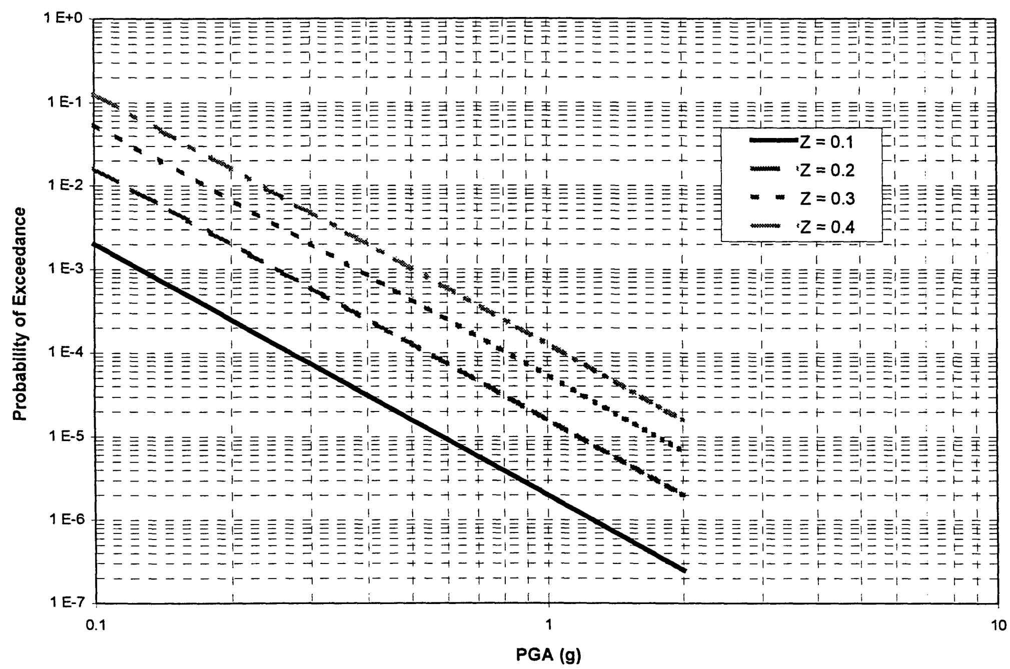


Figure 4-4: Resultant hazard curves used for Basic Score calculations

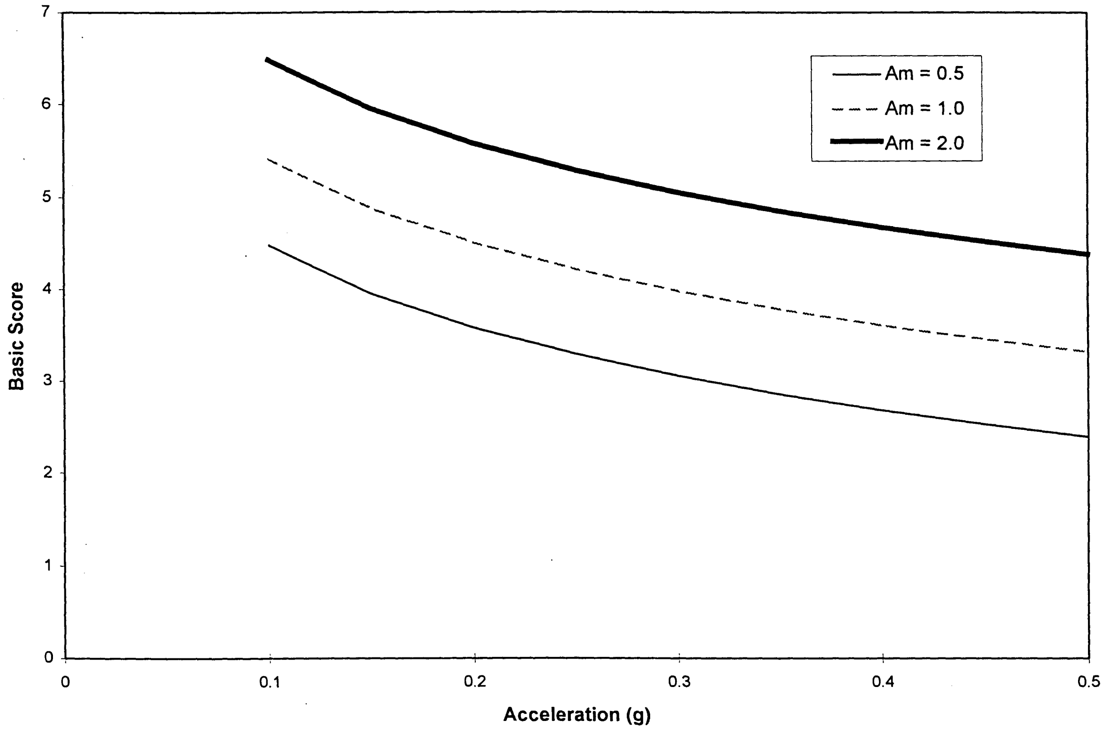


Figure 4-5: Scores based on annual probability of failure (Beta = 0.4)

SECTION 5

COMPONENT FRAGILITIES

This section describes in detail the methods used to quantify equipment vulnerability and the basis for application of various methods to different components. Examples are presented of detailed data used to generate fragility functions.

5.1 Application of Fragility Data for Equipment Components

Chapter 4 described the fragility function and the way in which it is used within the scoring method for this screening approach. That definition of fragility is a key component in the scoring method.

A major technical challenge of this program was to determine fragilities of major equipment components on a "generic" basis, even though we recognize that actual fragilities of specific installations are subject to substantial variability in properties and characteristics that would impact response in an earthquake.

For use in screening assessments, these fragilities would need to be applicable for a given equipment category (e.g. valves, fans, chillers, pumps) without specific prior knowledge of manufacturer, size, installation details, etc. In addition, fragilities would be needed for application to specific conditions that may exist in an equipment component, such as unanchored cabinets, valves subject to impact loads, or control panels with unsecured circuitry cards. Fragilities are needed to be applicable for every vulnerability for which a PMF is identified in the scoring system.

5.2 Sources of Component Fragility Data

As briefly discussed in Chapter 4, fragility data were generated using a variety of methods, depending on the amount and quality of available data. The following sections list the primary resources used for compiling data used to develop component fragilities.

5.2.1 Facilities Included in Earthquake Investigations

All of the methods used rely to some degree on detailed earthquake experience data. These data were collected from the investigation of earthquakes that have occurred throughout the world over the last two decades. The data include details of equipment and systems that were damaged in earthquakes, as well as systems that continued to function with or without damage.

A primary driving force for research into equipment and system performance has been the seismic equipment qualification requirements of nuclear power plants within the United States. Because of the cost involved in requalifying equipment that has been in service, as well as the safety hazards (e.g. radiation exposure from testing), nuclear utilities and the Electric Power

Research Institute (EPRI) have funded the development of equipment qualification methods utilizing actual earthquake data, rather than testing or finite element analysis of each component. Because most of the electrical and mechanical equipment in nuclear plant safety systems is also common to other industrial and commercial facilities, the types of facilities investigated and data collected have been diverse and extensive. For example, the types of facilities investigated for detailed data include:

- Power plants (fossil, hydroelectric, cogeneration)
- Electric distribution stations
- Petrochemical facilities
- Water treatment and pumping stations
- Manufacturing facilities
- Large industrial facilities
- Commercial facilities
- Hospitals
- Other facilities where access was granted to investigators

5.2.2 *Data Collected in Earthquake Investigations*

Most of the facilities were investigated in the days immediately following the earthquake, while damage was visible, and causes of damage could potentially be assessed or confirmed by the investigators. In many cases, detailed data were collected much longer after the earthquake, after the facility has been restored to full operations and damage has been repaired. At that time, inventories can be taken of damaged and undamaged items, ground motion records are accessible, and causes of damage and consequences are well known, as repairs and replacements have been made. Sources of data at a given facility include:

- **Interviews with facility management and operating personnel.** These typically provide the most reliable and detailed information on facility performance, especially with regards to functionality of systems before, during and following the earthquake.
- **Facility damage surveys.** These are detailed surveys of damage immediately following the earthquake, before repairs are made, or at a later date.
- **Facility operating logs.** Many facilities routinely maintain operating logs that would list problems associated with the earthquake and actions taken as a result. Damage is often documented in these logs. In addition, these logs provide

details on the time a facility or systems within a facility were out of operation following an earthquake, and problems encountered in the restart process.

- **Facility inspection reports.** Many facilities prepare internal detailed reports on the effects of the earthquake, including detailed documentation of all damage and system malfunctions.

- **Additional data collection.** In limited cases, facilities have made available very detailed data, such as design drawings of structures and mechanical and electrical systems, or seismic and other design criteria.

The primary emphasis on these investigations has always been to collect detailed, reliable data on damage. These data are considered as "perishable" and generally become less thorough and reliable beyond some length of time following the earthquake.

Of secondary importance is collection of detailed data regarding systems that were not damaged. Because of the time involved in collecting data, and the amount of cooperation required from each facility, including multiple visits to the site, success data by their nature tend to vary in detail from site to site. The extensive collection of detailed success data available for use on this project is a function of a large funding effort by nuclear utilities, EPRI, and EQE International, in conjunction with tremendous cooperation over a multi-year period from several hundred key facilities in dozens of earthquakes throughout the world (e.g., EQE 1988a,b, c, d, 1990, 1991a, b, 1996, 1997). More recently, NCEER and other organizations have funded several investigations (e.g., Swan and Harris 1993, Goltz 1994, and O'Rourke and Palmer 1994).

5.2.3 Other Published Data Sources

In addition to the first hand data collection, literature searches were conducted to identify documented damage from past and recent earthquakes. These literature searches were conducted over a period of several years and were funded by various sources. They include reviews of over 500 reports from some 170 earthquakes, over the last 100 years. These earthquakes have occurred throughout the world and are of varying magnitude. In many cases, details of the damage were not available and can not be determined. In other cases, details were provided of the cause and consequences. Generally, inventory of undamaged equipment is not provided in published literature.

For the 1994 Northridge, California earthquake, the authors have documented instances of damage to equipment and piping systems, or any other damage that may be considered "non-structural." A survey of 10 reports by government agencies, professional organizations, and consulting engineers identified over 400 specific references to damage. Note that some of these referrals are duplicates in multiple reports, while others document multiple damage scenarios. For example, a report by the Fire Sprinkler Advisory Board, Southern California provides the following information for St. Johns Hospital in Santa Monica, "Underground and overhead fire protection lines broken. Fittings, heads and hangers had to be replaced. C-clamps slid off flanges. Powder-driven fasteners failed."

In many of these examples, causes and consequences of damage are obvious, but without inventory data necessary for statistical calculations. However, PMFs have been developed that take into consideration causes of damage identified in literature searches.

The data from literature searches were collected and collated according to broad categories of non-structural components, equipment, tanks, cooling towers, etc. The information was used to identify vulnerabilities in specific equipment, but was generally not directly useful in development of fragility functions. Ground motion data were not always available for the sites described in published literature.

The raw data from the Northridge earthquake literature search are included in Appendix A to this report. These data are sorted by equipment or non-structural category. It is recognized that there are duplicate entries due to reporting in multiple sources.

Another example of results from a literature search is included as Appendix B to this report. That survey includes some 54 references for earthquakes that occurred throughout the world between 1987 and 1991. Again, the damage is sorted by broad equipment categories, with the description of the damage and cause (as reported in the reference document) listed.

In addition to those reports, other data bases and reports on the topic of non-structural damage were reviewed and used as appropriate. Examples include Association of Bay Area Governments (ABAG) (1990a,b, 1991), Phan and Taylor (1996) and EERI (1991).

5.2.4 Use of Formal Databases

Much of the raw data on success and failure of certain categories of equipment in earthquakes has been compiled by EQE into an electronic database (EQE, 1993). That database contains basically all of the relevant known data related to individual equipment items. This could include any or all of such information items as make, model, size, anchorage details, performance in specific earthquakes, etc. These data were used to develop statistical relationships where possible, as described in the following sections.

The authors of this report recognize there may be some misconceptions about the nature and contents of this database and its direct applicability to this study. As such, we would like to point out the following:

- The raw data contained in the electronic database is limited to certain specific categories of equipment, most of which deal with systems found in power plants. This study applied to many more systems and components in other types of facilities.
- The electronic database is not compiled in a manner that allows easy statistical application. Much of the data manipulation was done by hand or in spreadsheets.
- The raw data in the electronic database was interpreted and "filtered" for use in this study, as described in the following sections.

- The electronic database does not contain the complete set of raw data collected in earthquakes. The data should be considered a representative sample, although possibly biased conservatively towards damaged sites and equipment items, by the nature of the emphasis of earthquake investigations.

- The electronic database does not contain the data from literature searches, other than data that was also observed by the EQE engineers performing the investigations.

In summary, the authors wish to point out that although the earthquake experience database that may be known to practicing engineers was used as a reference for this project, the raw data was interpreted and manipulated, and the database was only a portion of the information supply required to perform this project. Literature searches and other compilation of raw data also provided a necessary, if not equally important contribution.

5.2.5 *Other Published Fragility Data*

Where available, existing published data were utilized. For example, a report by Lawrence Livermore National Laboratory (1988) gives a compilation of fragility information from available probabilistic risk assessments of nuclear power plants. That report includes a tabulation of predicted fragilities for over 2000 equipment items in 20 nuclear plants. The fragility information contained in the report was produced from limited fragility test data, qualification test data, extrapolation of design calculations, and engineering judgment.

It is recognized that these data were produced at different times and sometimes for different purposes, and they are not necessarily consistent. Judgment has been exercised in application of these data and interpretation of trends.

Likewise, failure data from a study by Eguchi (1991) was utilized for buried piping. That study presents the performance of various types of buried piping as a function of Modified Mercalli Intensity (MMI). The performance is expressed in terms of breaks per 1000 feet of buried pipe. Data points were used as conditional probabilities of failure for given levels of motion, such that a mean fragility curve could be fitted directly to the data.

Fragilities for storage tanks were calculated using methods developed by Manos (1986). Manos provides a method for calculate tank shell buckling capacities in terms of limit impulsive acceleration, given an overall geometry and wall thickness.

5.3 Use of Earthquake Experience Data to Calculate Fragilities

As discussed previously, several methods were used to calculate fragilities, depending on the amount, quality, and type of data available for a given type of equipment. For some categories of equipment, very detailed data are available on success and failure. For other types of equipment, only data on failures are available. Also, for calculation of PMFs, assumptions must be made regarding fragilities of items with little or no detailed information on inventories.

5.4 Survival Analysis

Survival analysis is a technique applicable for determining the probability of failure at a given PGA or the seismic fragility of a component based on seismic experience data in which both survival and failure data are explicitly used. The data are binary where the observations take one of the two possible forms, success or failure.

Given the random sample of PGAs, the reliability function could be estimated by either (1) noting the percentage or fraction of the sample which survives a given PGA, or (2) noting the PGA at which a given percentage or fraction of the sample still survives. If the reliability function were presented graphically, the first approach would be analogous to selecting a value on the abscissa (PGA) and determining the corresponding value on the ordinate (probability of survival). The second approach would be analogous to selecting a value on the ordinate and determining the corresponding value on the abscissa.

Although the two approaches appear to be identical, they are based upon different theoretical procedures. Either of the procedures can be used to present an observed reliability function, since they are equivalent if used in connection with large samples. However, the second method is more advantageous than the first when the problem involves terminated observations.

Terminated or censored observations exist because surviving components are not tested until failure, i.e., the data is censored at the survival level. When an item survives an earthquake with a PGA of 0.25g, we do not know the actual failure level; we only know that it can survive 0.25g. Using this method, at the PGA experienced at the location of each failure or malfunction, the expected percentage surviving is known.

To apply this method, the independent variable, in this case the PGA, is defined in intervals. The sample population within interval *i*, n_i, is the number of equipment items experiencing a PGA falling between the upper and lower bounds of the interval. N_i is the number of items surviving a PGA *at least* as great as that of the interval (within the interval or higher PGAs). The probability of survival within PGA interval *i* is estimated by the formula

$$r_i = (N_i + 1 - f_i) \ / \ N_i + 1$$

where f_i is the number of failures occurring within the interval and r_i is the probability of surviving interval *i*.

In order for an item to "survive" a particular PGA interval, it must also survive the intervals of lower PGA. Therefore the "reliability" or surviving through a PGA equivalent to the upper bound of interval *i* is the product of survival probabilities of the preceding intervals.

$$R_i = (N_1 + 1 - f_1)/(N_1 + 1) \times (N_2 + 1 - f_2)/(N_2 + 1) \times \ldots \times (N_i + 1 - f_i)/(N_i + 1)$$

the probability of failure, F_i, or the fragility, for the upper bound of interval *i* is given by:

$$F_i = 1 - R_i$$

Fragility functions using this method are assumed to conform to the lognormal distribution as described in Section 4. There is an infinite number of combinations of median capacity A_m and uncertainty β_c that will provide a mean fragility curve to match the discrete points. Fragility curves are selected to provide a best match using trial and error methods with reasonable values of uncertainty.

5.4.1 *Example of Survival Analysis*

The survival analysis methodology compares the number of failed units over a given range of ground motion to the total number of units over that range. With these data one can plot points of failure probability (fragility) vs. ground motion. A curve can then be fit to these points that represents the mean probability of failure for that equipment type.

To generate this curve, one needs to know the total number of occurrences of the equipment type, the total number of failures, and the site PGA for each piece of equipment. Using the following procedure, points on a fragility curve can be generated. The following points are generated for the equipment category of "fans".

1. The range of PGA values for all the facilities containing the equipment type is broken down into several intervals, each of which will generate one data point.

   As an example, for fans, detailed data have been collected on several hundred fans experiencing PGAs ranging from 0.2g to 0.64g. The PGA has been defined, along with the total inventory of fans, at each site.

   The PGA range can be broken into four intervals:

   0.20g - 0.20g (58 units and 8 failures),
   0.24g - 0.26g (95 units and 5 failures),
   0.30g - 0.47g (200 units and 27 failures), and
   0.50g - 0.64g (49 units and 7 failures).

2. For each interval, calculate the weighted average PGA using the following formula:

$$\left(\sum u(j) * PGA(j)\right) / U$$

   where:

   u(j) = the number of units at site j
   PGA(j) = the PGA at site j
   U = the total number of units in the intervals

   For fans, the weighted average PGAs are 0.20, 0.25,0.35, and 0.56g. These are the points at which the fragility function is plotted.

3. The probability of failure for each interval is then calculated, with the intervals defined in order of increasing PGA:

$$N(i) = \sum_{i}^{m} n(i)$$

$$r(i) = 1 - f(i)/(N(i)+1)$$

$$R(i) = R(i-1) * r(i), \quad R(1) = r(1)$$

$$F(i) = 1 - R(i)$$

where:

m	= the number of intervals
n_i	= the number of units in interval *i*
N_i	= the total number of units in intervals *i* through m (PGA equal to or higher than that of interval *i*
f_i	= the number of failed units in interval *i*
r_i	= 1 - failures in interval *i* as a fraction of the units in intervals *i* to m
R_i	= the probability of success of a unit in interval *i* through m
F_i	= the probability of failure of a unit in intervals *i* through m

Using our example:

Interval	Weighted Avg. PGA	n	N	f	r	R	F
1	0.20	58	402	8	0.980	0.980	0.020
2	0.25	95	344	5	0.986	0.966	0.034
3	0.35	200	249	27	0.892	0.862	0.138
4	0.56	49	49	7	0.86	0.741	0.259

4. The probability of failure is then plotted against the weighted average PGA for each interval.

5. A lognormally distributed mean capacity curve is then fit to these data points by iteratively adjusting values of the median acceleration capacity (A_m) and the logarithmic standard deviation value (β_c). This is shown for our example in Figure 5-1. It is important to note that there is an infinite number of combinations of parameters that can reasonably fit those data points. Values were chosen using typical uncertainty and randomness values.

5.4.2 *Definition of Failure*

Compilation of performance data includes a determination of number of "failures." Failure is usually defined as the inability of an equipment item to perform its intended function. However, the following considerations were included in performing these evaluations:

- Failure of multiple items by a "common cause" such as ground settlement may have been counted as one instance of damage. However, if 2 of 10 identical items failed because of inertial loads, it was considered as 2 failures.

- In many cases, equipment ceased to function only because of loss of power. If the equipment was not otherwise damaged, it was considered as "success" data.

- In many cases, equipment anchorage or restraints failed, and the equipment was restarted successfully after repairing the anchorage, without other damage. These instances were considered as "failure" because of the lack of capability to function, even though they may have been considered as "undamaged" by the facility.

5.4.3 *Limitations of Survival Analysis*

There are several limitations in the application of this method for fragility estimation for use in calculating Basic Scores and PMFs. One of the primary issues is that many types of equipment have very few documented failures. In addition, it is recognized that failure is not always a function of the site PGA, but rather construction details or other conditions. Cases with few failures and with failures primarily distributed in the low PGA range are not well suited to this methodology.

Another potential inconsistency with using this method lies in the definition of the "Basic Score." Where survival analysis is used, the Basic Score is in fact an indication of the reliability of that item without any knowledge of the actual conditions or vulnerabilities that might be present. This is inconsistent with the intended definition of the Basic Score as an indicator of the reliability of a "well designed" and "well installed" equipment item relative to normal construction practices. However, the following should also be noted:

- Low component and system scores are generally governed by PMFs rather than Basic Scores.

- Basic Scores only govern if no PMFs apply. The PMFs are calculated to achieve a specified total score; thus, if the Basic Score is artificially low, the PMF will be artificially low by the same amount, such that the final score after using the PMF is independent of the Basic Score.

- The review process included consideration of the relative scores of various equipment items with and without vulnerabilities. Where deemed important, some adjustments have been made for these inconsistent applications of fragility data.

It should also be noted that by fitting a lognormal fragility function to survival data, we are only trying to match the very tail of the S-shaped mean capacity curve to very few data points. This is a limitation of this method in the absence of true failure data incorporating testing to very high accelerations.

5.5 Survival Analysis with Limited Failures

Another analytical technique accounting for survival data at specified PGA levels was used for many equipment categories with limited or no failure data. Although there are some failures in the data, these are accounted for separately in the PMFs. This method then can be used to determine the distribution of capacities for components for which it has been determined through inspection that vulnerabilities that have caused damage in past earthquakes are not present.

It is conservatively assumed that components would fail just beyond the site PGA levels, i.e., all survival data is effectively transformed to failure limit data. Then, classical statistical procedures are valid and point estimates of sample mean and sample variance can be computed.

The following assumptions are made:

1. Failures within the sample would not have occurred had the vulnerabilities been discovered through a process such as use of the score sheets in this methodology.

2. There is a minimum value of PGA, below which equipment is assumed to have survived with considerable margin. For this study, 0.40g is selected as the cutoff.

3. Above the cutoff PGA, equipment survived the imposed seismic loading with some smaller margin. The margin of safety for these items is assumed to be 1.2, meaning that 20% more load would have caused failure.

4. Because the ground motion actually experienced at a site is variable, with no corrections made to account for attenuation differences between recording stations, embedment effects, or local soil conditions, we assume that the range of PGAs experienced could actually range from two standard deviations below the mean to two standard deviations above the mean of this range of PGAs.

5. The true failure envelope is assumed to be skewed toward the high end of this range such that capacity data follows an upper triangular distribution.

6. The equipment capacity is assumed to be distributed lognormally within the above sample statistics.

5.5.1 *Example of Fragility Estimation*

The formulation of a mean capacity curve using success data is illustrated in the following example for the equipment category of Fans, utilizing the same data as in Section 5.4:

- 125 components are found at 13 sites which experienced PGAs ranging above the cutoff of 0.40g. The mean PGA, m, for these sites is calculated to be 0.47g, with a standard deviation, s, of 0.08g.

- The lower bound of the upper triangular distribution,
  a = 1.2*(m-2s) = 0.37g.
  The upper bound of the upper triangular distribution,
  b = 1.2*(m+2s) = 0.76g.
  (the 1.2 represents the margin of safety.)

- The mean and standard deviation for an upper triangular distribution are defined as:

$$\mu = (a + 2b)/3 = 0.63$$
$$\sigma = \sqrt{(a^2 - 2ab + b^2)/18} = 0.09$$

- The lognormally distributed median capacity curve is defined by

$$\beta_r = \sqrt{\ln\left(1 + \sigma^2/\mu^2\right)} = 0.14 \quad \text{(the randomness factor)}$$

$$A_m = \sqrt{\mu/\left(1 + \beta^2\right)} = 0.62g \quad \text{(the median acceleration capacity)}$$

Figure 5-2 illustrates the results of this methodology compared with the survival analysis presented in Section 5.4 for the above case with a typical value of β_u of 0.4. Note that there is a great deal of sensitivity to uncertainty values that are selected.

5.5.2 *Other Considerations*

As with the survival data methodology of Section 5.4, several assumptions have been incorporated into this fragility estimate methodology. One underlying principle of this method is that all failure modes are accounted for in the PMFs. This is useful in that the number of survivals is emphasized, and it gets around the difficult problem of defining failures, and their dependence on parameters other than PGA.

It is observed from the study of equipment performance that the number of component failures is very small compared to the number of survivals. By concentrating on survivals instead of failures, the statistical conclusions will be conservative as typically only a fraction of actual survivals are recorded since engineers in the field usually concentrate on the collection of failure data, which is perishable.

5.6 Fragility Estimates From Limited Failure Data

Section 5.2 described the extensive research into equipment and other non-structural component performance in past earthquakes, in earthquake investigations and literature searches of damage. For several types of components, only limited failure data are available.

Reliable estimates of inventory and survival population have not or cannot be made. The statistical evaluations described in the previous sections therefore cannot be made.

This is also the situation for many conditions on which PMFs are required. We know from experience that certain vulnerabilities have caused failures, and we know the PGAs at sites where those failures have occurred. We do not know how many of the survival population had that vulnerability present.

In many of those cases, we have estimated the component fragility based on the lowest PGAs where damage was observed and estimates of uncertainty based on the quality and extent of our knowledge of the population and the extent of failures.

As discussed in Section 4, the value representing the High Confidence of a Low Probability of Failure (HCLPF) is generally defined as that with a 95% confidence of a 5% probability of exceedance. This is a value that can be calculated from the fragility curves.

Given the relationships between HCLPF, median capacity A_m and logarithmic standard deviation value β_c described earlier, a fragility can be completely described by defining two of these three variables. For this technique the HCLPF is estimated based on the lowest observed PGAs at which failures occur. This relies on a physical interpretation of the HCLPF as the "threshold of failure," or the PGA at which failures begin to be observed. Uncertainty values are assigned within a reasonable range based on our knowledge of the population and the number of failures.

5.7 Scores for Rugged Equipment

Some equipment items are inherently rugged. This refers to design and construction that gives the equipment the ability to survive strong motions without loss of function. This may result from empirical design for vibrational loads or transportation loads or due to a small mass. As an example, small devices like light switches or manual valves would be considered to have a very low probability of failure unless special conditions exist, such as a potential impact with an adjacent item.

For several such components, arbitrary basic scores have been assigned which are relatively high, reflecting expected good behavior in the absence of special negative conditions. Fragilities have not been calculated for these items.

5.8 Scores Derived by Other Methods

Basic scores and fragilities for certain categories of components have been developed using alternate methods than those described above. These cases are described in the following sections.

5.8.1 *Unanchored Vertical Tanks*

Flat-bottom vertical liquid storage tanks have sometimes failed with loss of contents during strong earthquake shaking. In some instances, the failure of storage tanks has brought about disastrous consequences, such as fires and polluted waterways.

The response of unanchored tanks during earthquakes is highly nonlinear and much more complex than implied in available design standards. The effect of shaking is to generate an overturning force on the tank which causes a portion of the tank baseplate to lift up from the foundation. While uplift itself may not cause serious damage, load reversal causes the uplifted segment to move down and impact the ground, causing high compression stresses in the tank shell.

The primary types of damage that have occurred in past earthquakes include the following:

- Buckling of the tank wall
- Failure of the weld between the baseplate and tank wall
- Roof damage due to sloshing
- Breakage of piping
- Splitting and leakage at riveted and bolted seams
- Collapse due to anchorage failure for tanks with high aspect ratio
- Buckling of thin-walled stainless steel tanks
- Cracking of fiber reinforced plastic tanks
- Tearing of tank walls due to overconstrained walkways connecting two tanks that experience differential movement
- Tearing of tank wall or tank bottom due to overconstrained stairways anchored at the foundation and tank shell

Tank shell buckling for steel tanks was chosen for the derivation of the basic scores. The other major vulnerabilities are used as the basis for PMFs.

The method of scoring for tanks is slightly different than for other components. For tanks, the user is expected to categorize the tank according to its geometry, comparing the diameter with the aspect ratio (height / diameter). That category is then used in a second matrix with the seismic zone to determine the earthquake load level used for basic scores. Amplification for tanks elevated within a building is accounted for by using a separate sheet.

A tank evaluation method developed by Manos has been selected for representing the seismic capacity. That method is based on experimental studies and observed behavior of tanks in past earthquakes. The tank is deemed stable if the limit impulsive acceleration, C_{eq}, is greater than the earthquake-induced peak spectral acceleration at 2% of critical damping.

The limit impulsive acceleration is defined as follows:

$$C_{eq} = \frac{0.372}{\rho_w} \frac{SE t_s^2}{GRH^2} \frac{m_t}{m_1} \left(\frac{R}{H}\right)^n \left(\frac{t_s}{t_p}\right)^{0.1}$$

where ρ_w = specific density of water; S = foundation coefficient; E = young's modulus; G = liquid density ratio; R = tank radius; H = tank height; m_t = total liquid mass; m_1 = liquid impulsive mass; t_s = tank wall thickness; t_p = bottom plate thickness. The ratio of m_1 to m_t is defined as follows:

$$m_1/m_t = \frac{\tanh(1.73R/H)}{(1.73R/H)} \quad \text{for } R/H \geq 0.667$$

$$m_1/m_t = 1 - 0.436R/H \quad \text{for } R/H < 0.667$$

The limit impulsive acceleration is related to the PGA as follows:

$$PGA = C_{eq} / 4.3$$

5.8.2 Piping

The general category of "piping" as used here includes pipes of any material, diameter, construction, and application as long as they are supported above ground and not buried. It generally also includes normal pipe-mounted components such as hand valves, pressure taps, thermocouples, gauges, filters, and traps.

Piping is common in every site that has experienced earthquake motion, even if only for domestic purposes such as potable water. Because of the broad usage of piping, it is very difficult to develop fragility estimates in a generic manner. It is very difficult to estimate an inventory of piping that has experienced earthquakes.

Piping is commonly referred to in terms of a number of "runs". A run of piping, as used here, is a portion of a piping system extending from one endpoint to another. Examples would be the run of pipe from a pump to a tank, or from a pump to an entry point into the ground. From a stress analysis standpoint, a "run" of pipe would generally refer to the portion of the system included in a single analytical model.

Earthquake damage to exposed piping is sufficiently rare that instances of leaks and fractures are generally recorded at earthquake sites investigated. It is possible therefore, to estimate a fragility function based on historic performance. At each site a rough estimate of the inventory of pipe runs can be made based on the type of facility.

PMFs can be developed based on failure data, similar to the method described earlier. Damage data was used to identify vulnerabilities that should be the focus of the screening evaluation.

In addition to earthquake data, data published by Lawrence Livermore National Laboratory, described in Section 5.2.4, has been used for piping. While the database of fragility values contains over 200 estimates for piping, many of those have been filtered out to exclude those that would have been expected to be designed specifically for seismic loads. However, many of the piping runs in eastern U.S. nuclear power plants may have been installed without specific analysis for seismic loads and would be considered typical of a "good" industrial installation. They would be considered to be unlikely to contain many of the most obvious vulnerabilities used for PMFs.

5.8.3 *Buried Piping*

Buried piping is also prominent at almost every site that has experienced earthquakes. While damage to buried piping has generally been catalogued, it is almost impossible to accurately estimate the inventory of buried piping runs within any given facility.

As mentioned previously, failure data from an empirical study by Eguchi (1991) was utilized for buried piping. Those data, in the form of plots, summarize the collective performance of buried piping of various materials as a function of ground shaking intensity. As with exposed piping, defining a "unit" of piping is somewhat arbitrary. Eguchi presents his data in terms of repairs per 1,000 feet of buried line. It should be noted that Eguchi illustrates wave propagation damage to piping buried in relatively firm ground, excluding damage due to sever settlement or liquefaction.

The plots of repairs per 1,000 feet are used for reasonable estimates of fragilities. The earthquake intensity can be correlated to peak ground acceleration using methods such as Trifunac (1976).

5.8.4 *Other System Components*

Some "components" of systems that lead to failure are related to events beyond control of the facility, such as offsite power, rather than physical equipment items. Offsite power fragilities have been based on data presented in the Lawrence Livermore study described in Section 5.2.4 and are generally quite low. The values are consistent with known experience in past earthquakes. There are no PMFs associated with component.

City water is another example of a highly variable component which is dependent upon items such as local soil conditions more than peak ground acceleration, and is generally beyond the control of the facility. PMFs address vulnerabilities to the system that may be present in certain conditions. The values used are based on very rough estimates of the amount of buried piping required to service a given facility.

5.9 Fragility Curves Used in Handbook

Section 1.2 describes the first phase of this project, where key systems were defined in four types of important facilities. Critical components deemed as "essential" for continuing operation are listed in Tables C-1 and C-2 of Appendix C. Those components have been included in determination of fragilities and scores.

Table C-3 in Appendix C identifies the specific fragility curves used for each component in Table C-1. Where scores or PMFs are associated with a fragility, the parameters of the curve are listed. Median capacity (A_m), combined uncertainty (β_c), and HCLPF values are tabulated. Actual fragility curves can be constructed using the methods of Chapter 4. The scores and PMFs used in the handbook are also shown.

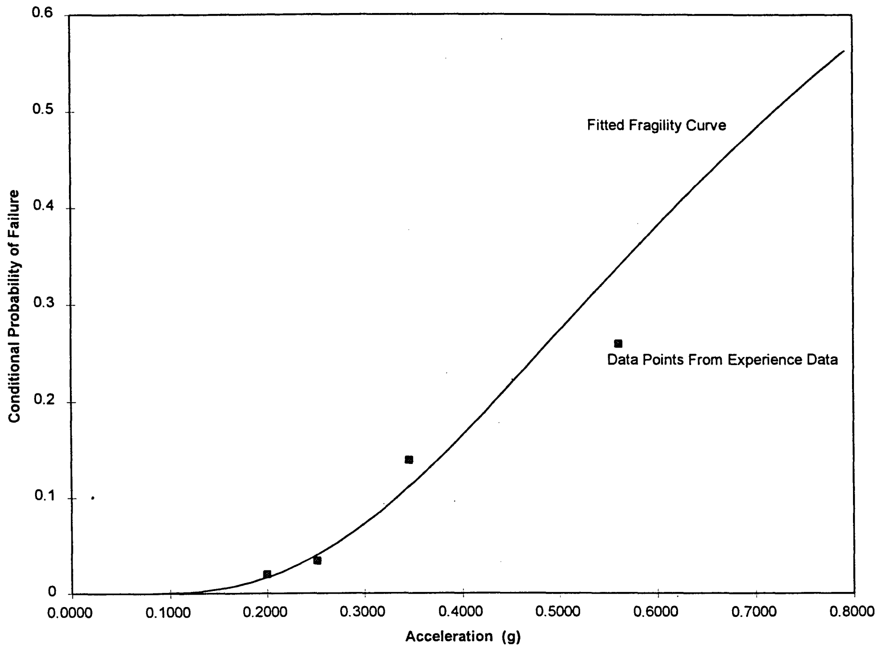


Figure 5-1: Fitting fragility curves to discrete points from earthquake experience data survival analysis

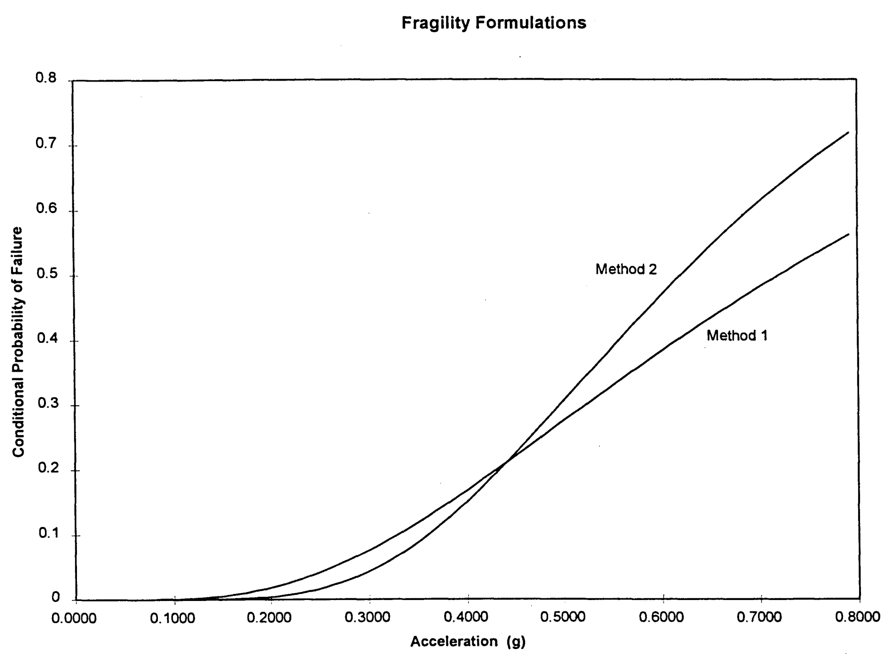


Figure 5-2: Example comparison of fragilities to match experience data using methods in Sections 5.4 (Method 1) and 5.5 (Method 2).

SECTION 6

DERIVATION OF SYSTEM SCORES

This section details the development of the scoring method as it applies to systems. A simplified method has been created that allows the user to combine the information gathered on various systems and their components into a score to be compared to other systems in the facility.

6.1 Development of the Systems Scoring System

An emphasis of this project was to develop a methodology that allows the user to make risk management decisions based on reliability of systems rather than individual components. In order to achieve that goal, a scoring system was developed, such that scores are assigned to individual components and to entire systems. Eventually a score can be assigned to every system required to maintain the operations capability of a given facility. Those scores are based on the scores of the individual components and the importance of those components in maintaining system function.

The derivation of component scores has been described in detail in previous chapters. Similar to the component scores, the systems scoring method is also developed so that a higher score indicates a higher system reliability.

6.2 Objectives of the Scoring System

For the scoring system to be successful it must meet several criteria:

- **Ease of Use.** The entire methodology described in this document is geared towards non-technical end users. Therefore the system scoring method must be accessible to this target audience and make use of values and concepts previously addressed.

- **Logical and Practical.** In addition to being simple, it must make sense, and treat more complex problems in a practical manner. The end user must believe that the results of the methodology are credible, given the intended limitations.

- **Reliable.** The results must be a reliable indicator of the system's relative vulnerability. Although the scoring method is not a rigorous analysis, it must be defensible, and use concepts and practices from the field of systems reliability.

6.3 Scoring for Redundant Systems

Chapter 3 discusses how to define critical elements in a system and their dependencies. One of the primary elements in determining reliability of a system is the amount of redundancy present. A redundant system or portion of a system is one where failure of one or more components will not necessarily shut down the system. The more redundancy present in a system, the higher the system score becomes. The scoring system must be chosen such that this effect is reflected in the system scores.

In order to achieve the objectives stated in Section 6.2, several methods were considered as potentially resulting in reasonable scores for redundant systems, and still practical to use in a simplified screening method.

Figures 6-1 and 6-2 show examples of the most simple ways that a simple scoring system could be implemented for a hypothetical group of redundant components. In Figure 6-1, the system score uses the largest score of the redundant components. In Figure 6-2, the system score is the sum of the two redundant components.

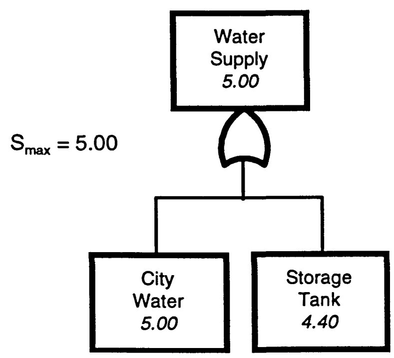


Figure 6-1

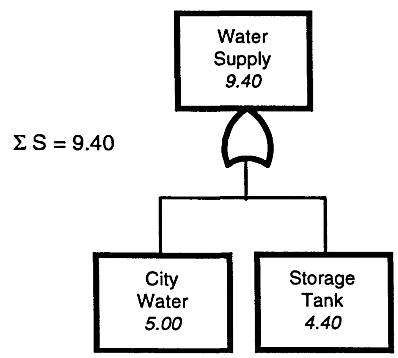


Figure 6-2

The two methods illustrated in Figures 6-1 and 6-2 provide vastly different system scores, and do not appear to adequately represent the impact on system reliability due to adding redundant components. Using the highest value ignores redundancies altogether, while summing the individual scores, as in Figure 6-2 appeared to overemphasize the benefits of redundancy.

6.3.1 Alternatives for Redundant System Scores

Several methods were tested in order to satisfy the objectives stated in Section 6.2. Several general formats for combining scores were identified that could be considered to be reasonably easy to apply. Those methods generally relied on either an average component score or the highest score, and the total number of redundant components. Various combinations of these were tested, as shown in Table 6-1.

Table 6-1. Redundant System Scoring Methods Considered

Number	Equation Form	Description
Method 1	S_{max}	Largest of the individual component scores (as in Figure 6-1)
Method 2	$\sum S$	Sum of the individual component scores (as in Figure 6-2)
Method 3	S_{avg}	Average of the individual component scores
Method 4	$S_{max} * (C_1 + C_2 * N)$	Largest component score scaled by a factor based linearly on the number of components (N)
Method 5	$S_{max} * C_3{}^{(C_4 * N)}$	Largest component score scaled by a factor based exponentially on the number of components (N)
Method 6	$S_{max} + (C_5 * N + C_6)$	Largest component score plus a factor based on the number of components (N)

6.3.2 *Systems Analyses*

The methods in Table 6-1 were tested by performing rigorous systems analyses of multiple cases with varying numbers of components. The test cases involved rigorous analyses of 100 independent, hypothetical groups of components, randomly generated. Each contained from 2 to 10 components with median capacities between 0.2g and 1.2g. For simplicity, the randomness and uncertainty factors for these components were kept constant at 0.35.

These data were used as input for analyses which generated an annual probability of failure for each group using a 0.1g seismic hazard curve. The annual probability of failure was converted into a basic score to compare with the results predicted by our methods.

Analyses were performed using the EQE proprietary program EQESRA™. EQESRA™ was developed to evaluate the probability distribution of system failure frequency from information about component fragilities (seismic or non-seismic failures), Boolean expressions for accident or event sequences, and seismic hazard. The program performs component combinations in accordance with the Boolean expression to yield an overall system or plant level fragility. It then convolves the system fragility with the seismic hazard to yield a probability distribution on failure frequency, which was translated into basic scores for comparison to results from the simplified methods. The EQESRA™ program uses the methodology described in Kaplan (1981) and Kaplan and Lin (1987).

6.3.3 *Results of Systems Analyses*

While a simplified method would not be expected to precisely match the results of a sophisticated analysis, we would want trends to be adequately captured. To judge which method best accomplishes this, a least squares fit was generated for the EQESRA™ results from the 100 test cases. For each simplified method, a least squares fit line was calculated. These fit lines were used as the basis for comparison.

Figure 6-3 shows the least squares fit lines for the data generated using Methods 1, 2 and 3 along with the fit line for the EQESRA™ results. The rigorous systems analysis approach using EQESRA™ suggests some increase in score as the number of components increases. As expected, Methods 1 and 3 do not reflect any higher reliability from adding redundant components. Method 3 is slightly less than Method 1 because it uses the average, rather than highest component score. Also as expected, Method 2 appears to grossly overestimate the benefits of redundancy. While all of these methods are easy to use, none of them provide sufficient accuracy to make results from this method credible.

Methods 4 through 6 are all modifications of Method 1. Each applies a factor to the maximum individual component score. The factors are based on the number of components in the redundant system. While all three factors have a different form, they can each be manipulated to provide results that mimic the results obtained using EQESRA™. Through an iterative process the equations for each method became:

Method 4 $S_{max} * (0.95 + 0.075 * N)$

Method 5 $S_{max} * 1.07^{(0.80 * N)}$

Method 6 $S_{max} + 0.50 * (N - 1)$

The least squares fit lines for these three methods (along with the one for the Method 1) are plotted against the EQESRA™ line in Figure 6-4. All three methods provide reasonable results compared to the rigorous analyses using EQESRA™. For ease of use, Method 6 is preferred since it requires only that a multiple of 0.5 be added to the highest component score.

The scores for the hypothetical components were all generated for a seismic hazard curve anchored at 0.1g at the 475 year return period (Zone 1 of the Uniform Building Code). To further validate Methods 4, 5 and 6, scores were generated using a seismic hazard curve anchored to 0.4g at 475 years (Zone 4 of the UBC). The results are shown in Figure 6-5 and further support the use of Method 6. Using the 0.1g hazard values, all three methods closely matched the EQESRA™ best fit. Using the 0.4g hazard values, Methods 3 and 4 appear to be sensitive to the parameters used, while only Method 6 continues to match the EQESRA™ values. Methods 3 and 4 could be made to match these values by adjusting their constants but this adds an undesired level of complexity to the process.

6.3.4 *Selection of Scoring Method*

Based on the results discussed above, Method 6 was selected as the most appropriate choice for combining scores for systems of redundant components. The method requires selecting the highest individual component score and adding to that score a multiple of 0.5 determined by the number of components in the system or group. The method is expressed in the following equation:

$$\text{Redundant System Score} = S_{max} + 0.5 * (N - 1) \qquad (6\text{-}1)$$

where:

S_{max} = maximum individual component score
N = number of system components

This method meets all three objectives described in Section 6.2. It is easy to use, and it provides results consistent with our benchmark program across a range of test cases. On a case by case basis this method diverges from the EQESRA™ results, sometimes by up to 20%. However, it provides a method of increasing the reliability of a system in a manner proportional to the amount of redundancy. While it cannot provide a accurate measure of system reliability for each individual system, it does mimic the trends predicted by more sophisticated algorithms.

6.4 Scoring For Dependent Systems

A dependent system is considered to be one where failure of any component will cause failure of the entire system. It is logical to expect that the system reliability will depend primarily upon the smallest score, i.e., be only as strong as its weakest link. However, multiple components with similar magnitude of scores would also be expected to lower the overall system score.

Similar to the analyses performed for redundant systems, three methods were evaluated for dependent systems which combine the lowest individual component score with the number of components. Those methods are shown in Table 6-2.

Table 6-2. Scoring Methods Considered for Dependent Systems

Number	Equation Form	Description
Method 1	S_{min}	Smallest of the individual component scores
Method 2	$S_{min} * (C_1 + C_2 * N)$	Smallest component score times a factor based on the number of components (N)
Method 3	$S_{min} + (C_3 + C_4 * N)$	Smallest component score plus a factor based on the number of components (N)

6.4.1 Systems Analyses

The same 100 test cases developed for the redundant system analyses were used for these analyses. When EQESRA™ was run, the Boolean operators were changed to reflect dependent rather than redundant systems. As with the redundant systems, least squares fit lines were used to compare the proposed methods to the EQESRA™ results.

6.4.2 Results of Systems Analyses

The constants that are part of Methods 2 and 3 were determined iteratively. In order to get a close match to the EQESRA™ results the formulas for these methods became:

Method 2 $0.95 * S_{min}$

Method 3 $S_{min} - 0.02 * (N + 10)$

Figure 6-6 shows comparison of least squares fit lines for all three methods and EQESRA™. Method 1 provides a good match of the trend indicated by the EQESRA™ results. It yields slightly larger scores than EQESRA™, as would be expected. The other two methods can match the magnitude of the EQESRA™ results better but they are not as simple to use as Method 1.

6.4.3 Selection of Scoring Method

Based on the results discussed above, Method 1 was selected as the most appropriate choice for combining scores for systems of dependent components. The method requires selecting the smallest individual component score. The method is expressed in the following equation:

$$\text{Dependent System Score} = Smin \quad (6\text{-}2)$$

where:
Smin = minimum individual component score

This method meets all three objectives described in Section 6.2. It is very easy to use, and it provides results consistent with our benchmark program across a range of test cases. While it cannot provide a accurate measure of system reliability for an individual system, it does correlate well with more sophisticated algorithms.

6.5 Summary of System Scoring Rules

The system diagrams and individual component scores are combined to generate system scores (as illustrated in Figure 5-1 of Part A) using the following two rules:

1. When a group of components is linked by an "**and**" gate (indicating dependency), the overall score for that group is the lowest of the component scores, S_{min}.

2. When a group of components is linked by an "**or**" gate (indicating redundancy), the overall score for that group is the highest of the component scores (S_{max}) plus a factor (f). This factor depends on the number of components (N) linked in parallel and takes the form: $f = 0.5(N-1)$. So the score for a redundant group of components is: $S_{max} + 0.5(N-1)$.

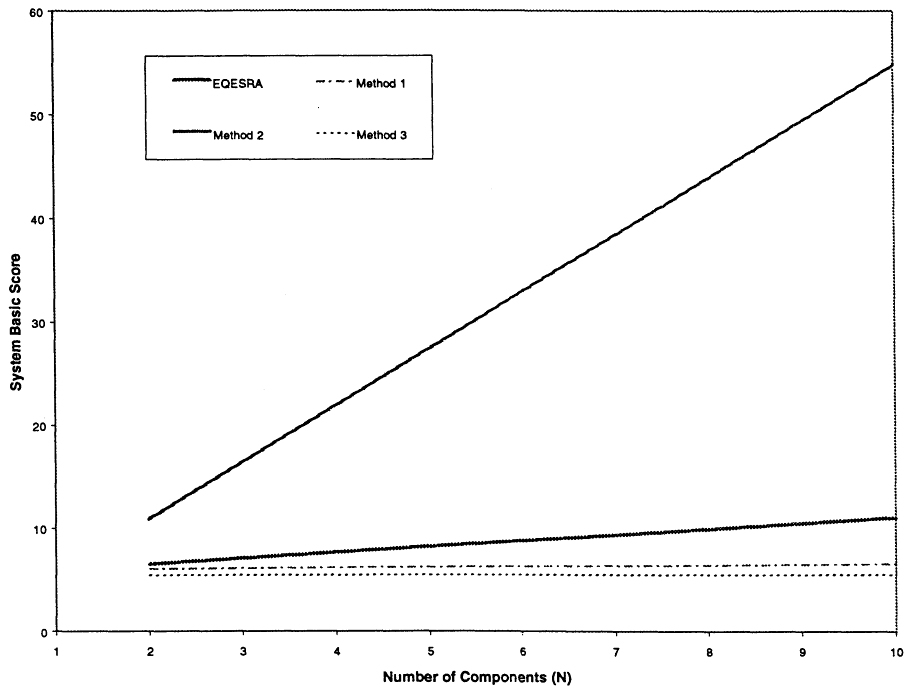


Figure 6-3: Redundant Methods 1, 2 and 3 versus EQESRA Results

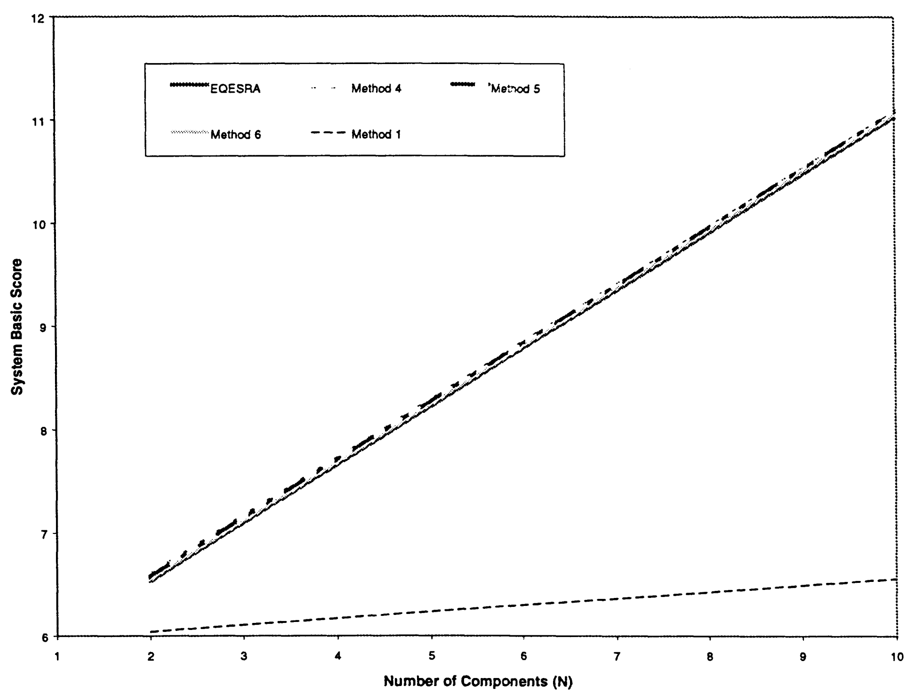


Figure 6-4: Redundant Methods 1, 4, 5 and 6 versus EQESRA Results

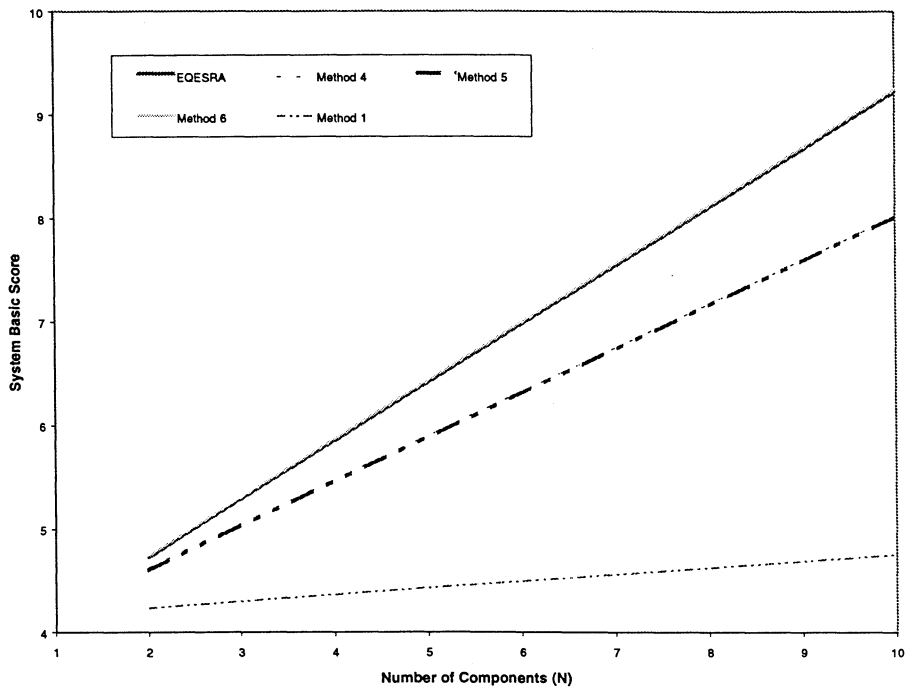


Figure 6-5: Redundant Methods 1, 4, 5 and 6 versus EQESRA Results for 0.4g Seismic Hazard Curve

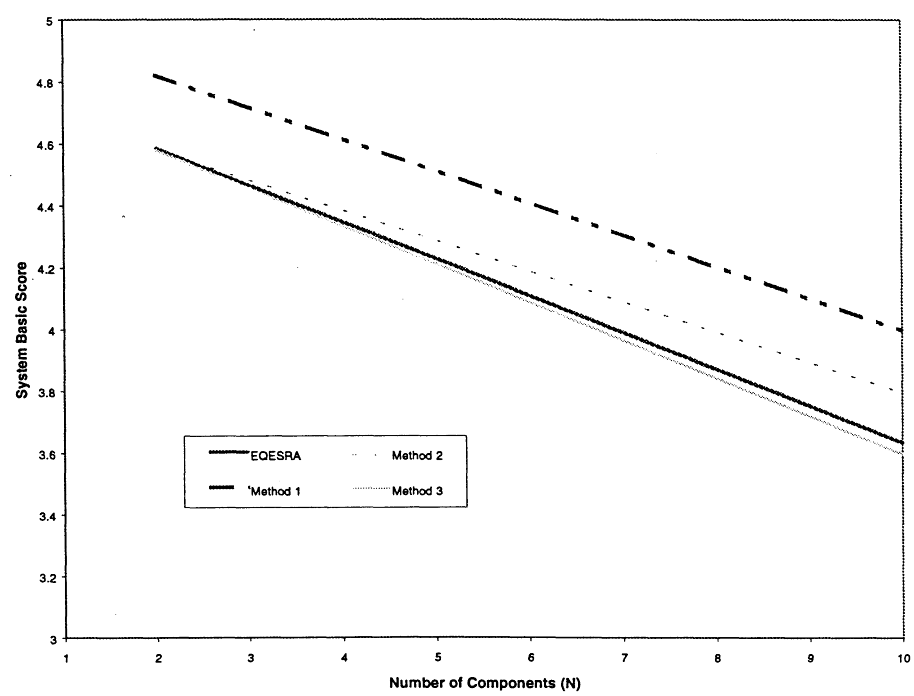


Figure 6-6: Dependent Methods versus EQESRA Results

SECTION 7

RISK MANAGEMENT

This section provides some additional background information on risk management, in conjunction with Section 6 of the Handbook.

7.1 Use of Risk Management

One of the goals of the overall methodology developed in this project was to incorporate risk principles into evaluation procedures. By using consequence-based, or performance-based criteria, analytical efforts and capital expenditures for upgrades can be prioritized and applied where they will achieve the most benefits.

Seismic issues have historically been the domain of structural engineers. The methods in the Handbook and this document rely on other disciplines and skills, such as mechanical and systems engineering. Risk mitigation efforts may also require the use of emergency planners, maintenance personnel, and others.

Evaluation of risk will usually identify a wide range of possible risk values and mitigation options. Deciding which risk-reduction method to use may be difficult. In most cases, appropriate decisions can be made without resorting to expensive analytical techniques. However, in some cases, particularly when mitigation options are very costly, quantitative risk analysis (QRA) techniques may be applied to measure the effectiveness of various options in mitigating the risk. This approach may also be used in prioritizing safety improvements and balancing cost and production issues.

7.2 Mitigation Options

This approach is not intended to be limited to life-safety issues, like most building codes for new designs. The benefits of a modification include factors that affect cost in many ways. Examples of losses that might occur in an earthquake include:

- Serious injury or fatalities
- Damage to properties, buildings, or environment
- Community economic or safety impact from the facility not being available
- Business interruption
- Loss of reputation (public perception of risk)
- Increased insurance costs
- Litigation and liability costs

The total loss in an earthquake is the sum of the losses in each of these categories. A review of the categories quickly leads one to conclude that the total loss may be significantly higher than the costs of repairing or replacing damaged buildings and equipment, and compensating personnel.

Determining the value of potential benefits from risk reduction is relatively straightforward for tangible losses, such as property damage, business interruption and increased insurance costs. However, intangible, such as loss of reputation or loss of market share, are difficult to quantify. A facility may experienced effects such as increased staff costs associated with public relations or possible employee attrition due to low morale.

This study did not focus on exhaustively identifying all possible risk reduction measures. Rather, it provides a framework in which risk measures can be weighed in a logical and practical manner. It was recognized that state-of-practice seismic assessments typically attempt to identify all problems and then mitigate them in some prioritized manner. The prioritization is usually the result of the perception of key people as to the importance of particular items in terms of safety and cost, and the possible consequences of failure.

The methodology here uses the same principles, but attempts to provide a methodical manner of quantifying issues, especially with regards to functionality, so that all issues and options are weighed consistently. The net result may be doing nothing.

The reader is referred to the Handbook for a more thorough discussion of various options and the steps taken in risk management.

SECTION 8

REFERENCES

Ang, A. H., and W. H. Tang. 1975. *Probability Concepts in Engineering Planning and Design, Volume 1 - Basic Principles.* John Wiley & Sons.

Association of Bay Area Governments (ABAG). November 1991. *Toxic Gas Releases in Earthquakes. Existing Programs, Sources, and Mitigation Strategies.*

Association of Bay Area Governments (ABAG). September 1990. *Hazardous Materials Problems in Earthquakes: Background Materials.*

Association of Bay Area Governments (ABAG). November 1990. *Hazardous Materials Problems in Earthquakes: A Guide to their Cause and Mitigation.*

Campbell, R. D., M. K. Ravindra, and R. C. Murray. September 1988. "Compilation of Fragility Information from Available Probabilistic Risk Assessments." UCID-20571, Revision 1. Livermore, CA: Lawrence Livermore National Laboratory.

Canadian Association for Earthquake Engineering. March 1994. "Preliminary Report on the Northridge, California, Earthquake of January 17, 1994." Reconnaissance Team. Association Canadienne du Genie Sismique.

Czarnecki, et al. September 1994. *Utilization of CSMIP Strong-Motion Records to Rationalize Horizontal Force Factors (Cp).*

Dames and Moore. "The Northridge Earthquake of January 17, 1994."

Drake, R. M. and R. E. Bachman. March, 1996. "NEHRP Provisions for 1994 for Nonstructural Components." *ASCE Journal of Architectural Engineering* 2 (1).

Earthquake Engineering Research Institute (EERI). October 1991. "Philippines Earthquake Reconnaissance Report." Supplement A to Volume 7.

Earthquake Engineering Research Institute (EERI). March 1994. "Northridge Earthquake, January 17, 1994." Preliminary Reconnaissance Report.

Electric Power Research Institute (EPRI). January 1988. "The 1986 North Palm Springs Earthquake: Effects on Power Facilities." EPRI NP-5607.

Electric Power Research Institute (EPRI). February 1988. "Investigation of the San Salvador Earthquake of October 10, 1986: Effects on Power and Industrial Facilities." EPRI NP-5616.

Electric Power Research Institute (EPRI). April 1988. "Effects of the 1985 Mexico Earthquake on Power and Industrial Facilities." EPRI NP-5784.

Electric Power Research Institute (EPRI). August 1988. "Reconnaissance Investigation of the March 2, 1987, New Zealand Earthquake." EPRI NP-5970.

Electric Power Research Institute (EPRI). December 1990. "The October 1, 1987, Whittier Earthquake: Effects on Selected Power, Industrial, and Commercial Facilities." EPRI NP-7126.

Electric Power Research Institute (EPRI). September 1991. "The October 17, 1989, Loma Prieta Earthquake: Effects on Selected Power and Industrial Facilities." EPRI NP-7500-M.

Electric Power Research Institute (EPRI). September 1991. "The October 17, 1989, Loma Prieta Earthquake: Effects on Selected Power and Industrial Facilities." EPRI NP-7500-SL.

Electric Power Research Institute (EPRI). January 1996. "The Island of Guam Earthquake of August 8, 1993: Effects on Electric Power Facilities." EPRI TR-106213.

Electric Power Research Institute (EPRI). July 1997. "Earthquake of October 9, 1995: Effects at the Manzanillo Power Plant." EPRI TR-108478.

Federal Emergency Management Agency (FEMA). September 1994. *Reducing the Risks of Nonstructural Earthquake Damage.*

Fire Sprinkler Advisory Board. "Northridge Earthquake, January 17, 1994." Southern California.

Goltz, J. D., ed. 1994. "The Northridge, California Earthquake of January 17, 1994: General Reconnaissance Report." Technical Report NCEER-94-0005.

Kaplan, S., and J. C. Lin. 1987. "An Improved Condensation Procedure in Discrete Probability Distribution Calculations." *Risk Analysis 7 (1).*

Kaplan, S. 1981. "On the Method of Discrete Probability Distributions in Risk and Reliability Calculations - Application to Seismic Risk Assessment." *Risk Analysis* 1 (3).

Le Val Lund. "Northridge Earthquake, January 17, 1994. Lifeline Introduction Water and Wastewater Lifeline Performance."

Manos, G. C. August, 1986. "Earthquake Tank-Wall Stability of Unanchored Tanks." *Journal of the Structural Division.* ASCE.

National Center for Earthquake Engineering Research (NCEER). March 1994. "The Northridge, California Earthquake of January 17, 1994: General Reconnaissance Report."

National Institute of Standards and Technology. March 1994. "Northridge Earthquake, Performance of Structures, Lifelines and Fire Protection Systems." NISTIR 5396.

O'Rourke, T. D., and M. C. Palmer. May 1994. "The Northridge, California Earthquake of January 17, 1994: Performance of Gas Transmission Pipelines." Technical Report NCEER-94-0011.

Phan, L. T., and A. W. Taylor. June 1996. "State of the Art Report on Seismic Design Requirements for Nonstructural Building Components." U.S. Department of Commerce.

Porter, K., G. S. Johnson, M. M. Zadeh, C. R. Scawthorn, and S. J. Eder. November 24, 1993. "Seismic Vulnerability of Equipment in Critical Facilities: Life-Safety and Operational Consequences." Technical Report NCEER-93-0022.

Swan, S. W., and S. K. Harris. September 1993. "The Island of Guam Earthquake of August 8, 1993." Technical Report NCEER-93-0017.

Swan, S. W. and N. G. Horstman. 1993. "Database System of Power Plant Equipment Seismic Experience." TR-102641. San Francisco, CA: EQE International.

Trifunac, M. D. 1976. "A Note on the Range of Peak Amplitudes of Recorded Accelerations, Velocities, and Displacements With Respect to the Modified Mercalli Intensity Scale." *Earthquake Notes* 47 (1): 9-24.

U.S. Department of Energy. February 1993. *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities.* DOE Standard 1020-92. Draft.

U.S. Federal Emergency Management Agency. July 1988. *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook.* ATC-21, FEMA 154.

U.S. Federal Emergency Management Agency. September 1988. *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation.* ATC-21-1, FEMA 154.

Appendix A

Literature Search: Performance of Nonstructural Components During the Northridge Earthquake

References for Northridge Earthquake Damage Literature Search:

1. Goltz, J. D., ed. 1994. "The Northridge, California Earthquake of January 17, 1994: General Reconnaissance Report." Technical Report NCEER-94-0005.

2. Canadian Association for Earthquake Engineering. March 1994. "Preliminary Report on the Northridge, California, Earthquake of January 17, 1994." Reconnaissance Team. Association Canadienne du Genie Sismique.

3. Earthquake Engineering Research Institute (EERI). March 1994. "Northridge Earthquake, January 17, 1994." Preliminary Reconnaissance Report.

4. Fire Sprinkler Advisory Board. "Northridge Earthquake, January 17, 1994." Southern California.

5. National Institute of Standards and Technology. March 1994. "Northridge Earthquake, Performance of Structures, Lifelines and Fire Protection Systems." NISTIR 5396.

6. Dames and Moore. "The Northridge Earthquake of January 17, 1994."

7. Le Val Lund. "Northridge Earthquake, January 17, 1994. Lifeline Introduction Water and Wastewater Lifeline Performance."

8. "Performance of Nonstructural Elements." August 1994. Background Report B19. Draft.

9. Czarnecki, et al. September 1994. *Utilization of CSMIP Strong-Motion Records to Rationalize Horizontal Force Factors (Cp).*

Location	Category	Description	Ref.
Water Treatment Plants	Baffles	Damage to wooden baffles in the concrete basins of water treatment plants.	1 (4-3)
LA County water reclamation plants - 15 mgd	Basins Equipment	Cracks and leakage in several concrete basins. Damage to process equipment such as aerators and associated piping, clarifier flights (scappers) and chains, and odor covers (bend downwards from sloshing suction).	1 (4-9)
Various Central Offices	Batteries	There is evidence of toppling of battery racks and acid spills. Two battery racks in the CO nearest the epicenter were damaged by a collapsed wall.	3 (73)
Unknown cogeneration plant	Boiler	Automatic closure of seismic gas shut-off valve isolated gas to the boiler. Backup power to restart was provided by a manual start DG.	1 (3-50)
Cogeneration Facilities	Boiler Valves	Automatic closure of a seismic gas shut-off valve isolated gas to the boiler. Backup power to restart the boiler was provided by a manual start diesel generator, enabling plant operation following resetting of the gas valve.	3 (77)
Balboa Blvd. Grenada Hills	Buried Piping	Water main damaged due to ground deformation. Three gas, three water, two sewer, and one oil line, 34.5kV-4.8kV, telephone, cable TV, and street lighting.	1 (2-13, 2-15)
550 mgd Water Treatment Plant	Buried Piping	84" diameter inlet line damaged due to tensile failure from liquefaction and lateral spreading of local soils. Other damage to 77 and 120-inch steel pipelines.	1 (4-3, 4-4)
600 mgd Water Treatment Plant	Buried Piping Conduit	Typical 6-8" settlement of soils adjacent to concrete basins severed several buried electrical conduits and chlorine solution lines.	1 (4-3, 4-5)
San Fernando Valley, Santa Clarita Valley	Buried Piping	Damage to water distribution pipeline network within epicentral area. Preliminary reports of 1200 leaks in San Fernando Valley and 300 in Santa Clarita Valley. Pipes were broken by compression and tension and weakened by corrosion due most likely to vibration and tectonic movement.	1 (4-9)
Balboa Blvd. Grenada Hills	Buried Piping	Three gas, three water, two sewer, and one oil line, 34.5kV-4.8kV, telephone, cable TV, and street lighting co-located. Ground movement caused breakage of underground pipelines, and a fire in the street ultimately burned the overhead lines and five homes.	1 (4-9)
Wastewater collection systems in San Fernando and Santa Clarita Valleys	Buried Piping	Settlement around manholes and cracking of sewer lines. Sewer line cracks typically occurred in clay pipe and included crown (top of pipe) collapses or cave-ins, pushed in sidewalls, and joint misalignments. Over 12 miles of sewer mains inspected, with 4% found to be damaged with 1% needing immediate repairs.	1 (4-11)
LA Metropolitan Area Natural Gas System	Buried Piping	Two months after earthquake, 624 repairs to distribution mains and services. 394 to metallic piping with evidence of corrosion, and 197 repairs in steel mains and services with no corrosion observed. 36 repairs in polyethylene pipes, the majority at couplings and transition fittings. 35 non-corrosion related repairs in transmission system, 27 at cracked or ruptured oxy-acetylene girth welds in pre-1932 pipelines. 2 on 12" transmission pipelines at locations of corrosion.	1 (4-16)
Balboa Blvd.	Buried Piping	Gas pipeline damage on a 22" steel pipeline constructed in 1930 with unshielded electric arc girth welds. Failed in tension at zone of tensile ground deformation.	1 (4-18)

Location	Category	Description	Ref.
Balboa Blvd.	Buried Piping	49" and 68" water trunk lines failed in tension and compression in tensile and compressive zones of ground deformation, respectively.	1 (4-19, 4-22, 4-23)
Holy Cross Medical Center	Buried Piping	The buried incoming fire water line had failure at the slip joints.	1 (5-11)
Pacoima, Wolfskill Street	Buried Piping	10" oil pipeline ruptured, spilling thousands of gallons of crude oil onto Wolfskill St., east of Laurel Canyon Blvd. Oil ignited destroying 2 houses and 17 cars.	1 (6-5)
Various water supply	Buried Piping	Bell and spigot piping damaged in a number of instances where bell was cracked at the curvature point where it changes diameter.	1 (8-5)
Royal Port Marina	Buried Piping	Pipeline ruptured by lateral spreading.	2 (80)
Balboa and Rinaldi	Buried Piping	Water and gas lines damaged by ground rupture.	2 (85)
Balboa Overpass	Buried Piping	Ruptured water main.	2 (86)
Natural gas system	Buried Piping	232 non-corrosion metal pipe failures directly caused by the earthquake. 35 were failures of major transmission lines of up to 36" diam. metal pipes. Fractures and yielding result of ground motion and relative displacements. In LA area local distribution system, 118 distribution main and 79 surface line failures (up to 16" diam.). 52 plastic polyethylene gas line failures still under investigation.	2 (89)
Balboa and Rinaldi, Grenada Hills	Buried Piping	One 22" pre-WW2 steel pipe ruptured, due to brittle fracture failure at some of the welds.	2 (89)
Sylmar San Fernando	Buried Piping	Rupture gas lines destroyed more than 70 mobile homes in Sylmar and San Fernando.	2 (89)
Water Distribution System	Buried Piping	20 major trunk lines of steel pipes 36"-100", over 1200 smaller local distribution mains of 6"-12" ductile iron pipes damaged.	2 (90)
Balboa Avenue	Buried Piping	Severe ground motion caused rupture of a 42" water trunk line over a distance of more than 2 city blocks.	2 (90, 95)
Pipelines feeding water treatment facilities	Buried Piping	Breaks in all 4 pipelines that feed water to the region's three water treatment facilities	5 (132)
Jensen Water Treatment Plant Sylmar	Buried Piping	Leaks in pipelines and at construction joints.	5 (132)
LA Aqueduct No. 2 at Terminal Hill	Buried Piping	77" steel pipe damaged. Pipe separated from its supporting saddle at several places and pipe sections bulged at other locations (3-6") along the alignment. Two sections were pulled apart at a mechanical coupling. Welds of brackets to pipes broke.	5 (132, 135, 136)
Balboa Blvd.	Buried Piping	22" gas main ruptured due to compressional ground failure. 6" gas line and 68" Rinaldi trunk water line ruptured.	5 (138-141)

Location	Category	Description	Ref.
Balboa Blvd.	Buried Piping	22" gas line and 48" water main failed due to ground extension. Pipes pulled apart.	5 (138, 141)
Balboa Blvd.	Buried Piping	Excavated section just N. of the fire site revealed 6" gas distribution line ruptured.	5 (138)
San Joaquin Valley - Refineries	Buried Piping	Several cracked welds at locations along a 10" pipeline transporting crude oil to refineries from San Joaquin Valley. Oil spill along Santa Clara River.	5 (138)
Water Supply System	Buried Piping	The water supply system failed to provide service to customers because of widespread damage to the water supply distribution system.	5 (149)
Natural Gas System	Buried Piping	The earthquake resulted in relatively more ruptures in the natural gas distribution lines than in the transmission lines, when compared with 1971. Most breaks occurred to older steel pipes, whereas plastic pipes performed well. Over 1300 breaks and leaks in the gas piping system were reported.	5 (149, 167)
Balboa Blvd.	Buried Piping	Contractional failures occurred on 3 pipelines: a 61" water line, a 22" gas line, and a 6" gas distribution line. The contraction of the 6" line showed coaxial shortening of approx. 14". Extensional failures occurred upslope. Several pipelines appeared to have pulled apart in approximately the same area, by about 9", with little or no lateral displacement of the pipelines.	3 (6)
Jensen Filtration Plant (Metropolitan Water District)	Buried Piping	Following the earthquake, the plant was taken out of service owing to the rupture of the influent conduit, an 85" steel pipe. The rupture occurred within existing engineered fill where cracking was evident in the adjacent slope.	3 (24, 25)
Water Distribution System	Buried Piping	Over 1200 leaks in the water lines and service connections in the San Fernando Valley and approx. 300 leaks in Santa Clarita Valley. Pipes, some previously weakened by corrosion, were broken in compression and tension, most likely because of permanent ground deformations. A bell on a bell and spigot connection was split.	3 (69-70)
Balboa Blvd. Granada Hills	Buried Piping	Ground movement caused breakage of underground piping.	3 (70)
Natural Gas System	Buried Piping	Preliminary reports (2/2/94) of 1377 breaks and leaks in piping system 489 in distribution lines, 35 in transmission lines, and 853 in service connection lines. Transmission line damage to steel lines, none to plastic lines (all lines <60 psi).	3 (71)
Balboa Blvd.	Buried Piping	22" line suffered two breaks, one in tension, one in compression. Fire occurred at tension break where pipe separated 9".	3 (71)
Gas and Water Distribution Pipelines	Buried Piping	Gas and water distribution pipelines had hundreds of breaks and restoration took several days.	6 (1)
Balboa Blvd. and Rinaldi St.	Buried Piping	Natural gas pipeline and water main breaks caused by the earthquake were responsible for five homes being destroyed by fire. The rupture was due to extensive ground cracking with compressional, extensional, and left-lateral deformation.	6 (2, 3)
King Harbor Marina Redondo Beach	Buried Piping	8" water main broke.	6 (6)

Location	Category	Description	Ref.
Angelo Drive / Mulholland Area	Buried Piping	Sewer lines damaged in this area. The western portion of Angelo Drive may have moved roughly 8" laterally while the eastern portion remained in its original position.	6 (7)
Jensen Filtration Plant Granada Hills	Buried Piping	Plant was shut down due to rupture of an 84" steel influent conduit.	6 (8)
Water Distribution System	Buried Piping	1200 leaks in San Fernando Valley. 300 in Santa Clarita Valley. Compression and tension failures occurred, and preexisting corrosion may have contributed to failure.	6 (16)
Gas System	Buried Piping	Major gas line breaks associated with ground rupture (not fault rupture). Initial reports of less than 1000 breaks and leaks, 95% in distribution lines and 5% in transmission lines. All breaks in the low -pressure (<60 psi) distribution system were in steel components.	6 (16)
Van Nuys Wastewater Reclamation Plant	Buried Piping	Broken underground water lines.	6 (17)
Jensen Filtration Plant	Buried Piping	Soil settlements of up to 15 cm and lateral movement up to 8 cm damaged buried conduit, a 210 cm welded steel line, and a 15 cm PVC chlorine line	7 (52)
LA Aqueduct Filtration Plant	Buried Piping	Possible liquefaction and settlement caused extensive damage to basins and piping.	7 (53)
LADWP	Buried Piping	Pipeline breaks/leaks in the distribtion system included 20 in the major trunks, more than 450 in mains, and several hundred in smaller lines.	7 (54)
Various	Buried piping	Approximately 1400 leaks reported in mains and services by the various utilities. Most affected were older cast iron with rigid joints and older (corroded) steel lines.	8 (8)
Hallmark Cards, Northridge Mall	Ceiling	50% of ceiling failed. (i.e. 50% of panels fell)	2 (183, 190)
PENGUIN's Store, Northridge Mall	Ceiling	Ceiling failed. Lights fell to floor.	2 (183, 191)
CARPETERIOR, Northridge Fashion Mall	Ceiling	100% ceiling failure. Lights down. Diffusers down.	2 (183, 192)
LEVITZ, Northridge Fashion Mall	Ceiling	Ceiling in display areas failed. Lights and diffusers fell to floor.	2 (184, 193)
LAFD Executive Offices	Ceiling	Ceiling in the reception area failed. Tiles and light lenses fell to the floor.	2 (252)
El Camino High School 5440 Valley Circle Woodland Hills	Ceiling	All T-bar ceilings fell.	4 (I-06)
Donald C. Tillman Water Reclamation Plant 600 Woodley Ave. Van Nuys	Ceiling	Maintenance building suffered fallen ceiling tiles and air ducts in its offices.	5 (133)

Location	Category	Description	Ref.
Airports	Ceiling Piping	Airport facilities suffered typical types of non-structural damage, such as fallen ceiling tiles and leakage of water pipes.	5 (146)
Northridge Hospital Medical Center	Ceilings Lights	Neonatal unit was evacuated due to ceiling and lighting damage.	1 (5-11)
LA Public Library, Northridge Branch	Ceilings	Ceiling failure, lights, diffusers and panels fell to the floor.	2 (183, 188)
VONS Store, Northridge Mall	Ceilings	Ceiling failed. Most lights OK - some fell. Diffusers dropped.	2 (183, 189)
UCLA	Ceilings	Surveys of ceilings showed that the localized areas where suspended light-weight ceiling damage occurred were caused by lack of current bracing details, frequently because the four-way diagonal bracing sets were not installed where ducts or other plenum components interfered.	3 (57)
Levitz Northridge Fashion Center	Ceilings Lights	Strip lights fell. Ceilings along with lights and diffusers fell. Some gypsum board ceiling areas broke from supports and were hanging down almost to the floor. Fluorescent strip lights fell.	3 (57, 58)
Carpeteria Store Northridge Fashion Center	Ceilings Lights	All of the suspended ceiling fell or was damaged. Lights and diffusers also fell.	3 (57, 58)
UCLA	Ceilings	In an auditorium, an entire area of plaster ceiling 15' x 75' fell when welds connecting thin gage channel hangers to heavier steel framing above failed.	3 (59)
Olive View Medical Center Sylmar	Ceilings	Some rooms had perimeter damage.	3 (63)
Veterans Administration Medical Center, Sepulveda	Ceilings	Larger ceiling areas, especially in auditorium and theater, were extensively damaged and large areas fell.	3 (65)
USC Healthcare Consultation Building	Ceilings	Suspended ceiling tiles and T-bar grids were distorted, but no ceiling components fell.	3 (66)
LA County Fire Dept. Executive Offices	Ceilings	The ceiling in the reception area was damaged and tiles and light fixture diffusers fell.	3 (66)
Central Office with service control center	Ceilings Lights Desktop Equipment	The CO had fallen ceiling panels, lighting fixtures and other items such as desk top computers.	3 (73)
Kennedy High School	Ceilings	Collapsed suspended ceiling.	3 (App.)
Central Offices	Ceilings	In many facilities ceiling tiles and lighting fixtures fell.	6 (17)

Location	Category	Description	Ref.
Furniture Store Northridge	Ceilings	Total interior partition and suspended ceiling collapse.	6 (25)
Various	Ceilings	Several instances of fully or partially collapsed ceilings. Ceilings without compression struts were able to move without restraint, resulting in dislodged acoustic tiles and bent T-bar grids. Ceilings with struts were damaged also. Often ceilings collapsed around perimeters of rooms due to inadequate ceiling sway bracing and pounding of walls against the ceiling.	6 (25, 26)
Hospital in Sylmar	Ceilings	Failure of shot in anchors supporting soffit	10 (7-7)
Northridge Fashion Center	Ceilings	Stucco breezeway ceiling detached from concrete frame and fell to the floor.	1 (5-2, 5-3)
Olive View Medical Center	Ceilings	Ceiling tiles fell, but lights were restrained by safety wires. In one egress area, two lights swung down when safety wire attachments failed.	1 (5-10)
Cal State Northridge	Chemical Spill	A fire started as a result of a chemical spill.	5 (153, 154, 157)
Northridge	Chemical Spill	64 car freight train detailed. 8000 gal of sulfuric acid spilled from one car. 2000 gal of diesel fuel spilled from the locomotive.	3 (85)
Cal State Northridge	Chemical Spill	Chemical fire on second floor of Science 2 building at CSUN.	3 (96)
Northridge Hospital Medical Center	Chemical spill	Formaldehyde spill occurred in an emergency room.	1 (5-11)
Northridge	Chemical spill	Train derailment resulted in the spill of 30,000 liters (8000 gal) of sulfuric acid and 7500 liters (2000 gal) of diesel fuel.	5 (146, 147)
Department Store Sherman Oaks	Chillers	Anchorage of two roof-top chillers in a three story shear wall building failed as a result of shallow embedment depth.	7 (21)
Olive View Hospital	Chillers	Two chillers on the roof failed their seismically designed vibration isolators, damaging connected piping.	7 (37)~
Several central offices	Circuit cards	In several central offices, circuit cards were shaken loose on the switches, which required manual reinsertion.	1 (4-3)
Unknown water reclamation plant.	Clarifiers	Sloshing caused jamming of the chain drive sludge scrapers in 7 of 44 final clarifiers.	1 (8-5)
Donald C. Tillman Water Reclamation Plant 600 Woodley Ave. Van Nuys	Clarifiers	Damage to five of 22 final clarifier tanks built in 1991. Sludge scapper damaged.	5 (133, 137)
Manufacturing Facilities	Compressed Gas Bottles	Some facilities experienced problems with gas bottles tipping over. Chains and straps were not effective.	6 (24)

Location	Category	Description	Ref.
Hospital in Palo Alto	Compressed gas cylinders	Some gas cylinders toppled where chained only at mid-height.	10 (7-3)
Fire Command and Control Facility	Computer equipment	Computer printer terminals shifted 6" in the computer room (two story base isolated building)	2 (251)
Electronic Data Processing and Manufacturing Facilities	Computer Floors	No reports of raised computer floors collapsed, but some computer floor panels buckled and slid over adjacent panels, leaving holes in the floor. In a few instances the caster-mounted computer equipment rolled into such holes and tipped, although not completely over.	6 (23)
Electronic Data Processing and Manufacturing Facilities	Computers	Some rigidly mounted mainframes used in manufacturing functions as well as controllers for elevators were violently shaken such that sides and doors on the equipment were thrown free and some contents, such as printed circuit boards, were dislodged.	6 (23)
Unknown cogeneration plants	Control systems	Control logic malfunctions are a significant factor for the restart of units undamaged by the earthquake	1 (3-49)
Burbank Power Plant	Crane	Damage to a crane.	3 (77)
Various	Desktop Equipment	Laser printers and desktop copy machines thrown to the floor (as opposed to "walking" off of supporting surfaces).	1 (5-11)
Central Offices	Desktop equipment	Desktop computers and other equipment were damaged.	6 (17)
Olive View Medical Center Sylmar	Electrical Equipment	A piece of electrical equipment at the penthouse level pulled out expansion bolts.	3 (64)
Hospital in Sylmar	Electrical Equipment	Panels were top braced. Some welded top bracing failed. Some panels shifted out at bottom.	10 (7-7)
Various	Electrical Equipment	In some cases, equipment moved, causing electrical wiring or chilled water lines to break.	6 (27)
Electronic Data Processing and Manufacturing Facilities	Electronic Equipment	Tall narrow electronic test equipment and mainframes supported on low-friction levelers or casters tended to roll around on the floor without tipping over.	6 (23)
Olive View Medical Center	Elevators	Several elevator counterweights bent their rails and pulled away.	1 (5-11)
Holy Cross Medical Center	Elevators	Not functioning.	1 (5-11)
Olive View Medical Center Sylmar	Elevators	Two elevators had counterweight damage.	3 (63)
Various	Elevators	688 instances where counterweights came out of guide rails. Occupants had to be rescued from 39 elevators.	9 (5)

Location	Category	Description	Ref.
Hospital in Sylmar	Elevators	Bolts sheared off housing for elevator machinery	10 (7-7)
Beverage can facility, Chatsworth	Equipment	Air converor system must be completely replaced	1 (3-49)
160,000 sq. ft. industrial facility, Chatsworth	Equipment	Anchorage failures	1 (3-49)
AES Placerita Power Plant, Newhall	Equipment	Tie downs of many pieces of heavy equipment in the power plant failed.	2 (94)
Beverage Can Company Chatsworth	Equipment	Suffered extensive damage to manufacturing equipment and to mechanical / electrical support equipment. Large ovens and other equipment pulled their anchors and shifted 1-2".	3 (75)
Beverage Can Company Chatsworth	Equipment	Air conveyor system had to be completely replaced.	3 (75)
Van Nuys Wastewater Reclamation Plant	Equipment	Damage to wooden sludge scraper flights.	6 (17)
Electronic Data Processing and Manufacturing Facilities	Equipment	Damage on 2nd floor of 2 story bldg. 3-5 times greater than similar equipment on first floor. Damage occurred primarily as a result of equipment sliding off of tables or desks, tall narrow cabinets overturning, shorter items on rollers or levelers sliding around and pounding into adjacent walls or other equipment, or falling into computer floor penetrations. When anchored, the forces in some cases caused damage to internal components.	6 (22)
Various	Equipment	Numerous cases of spring-isolated equipment mounted on building roofs moved from their foundation.	6 (27)
Huntington Beach	Equipment	Several rooftop units walked off their vibration isolators.	6 (27)
Valencia Water Reclamation Plant	Equipment	All solids collection equipment failed. Air diffusion and odor scrubber units were damaged. damage to chemical lab equipment and automatic samplers.	8 (14)
Tillman Water Reclamation Plant	Equipment	Sloshing caused jamming of the chain drive sludge scrapers in 7 out of 44 final clarifiers	8 (15)
Aliso Canyon Gas Storage Field Santa Susana Mountains N of Granada Hills	Fans	Structural damage to fan units used to cool compressed gas.	3 (71)
Large data processing center	Files, PCs, Workstations	Not bolted down, fell to floor	1 (3-47)
Cal State Northridge	Fire	Three fires occurred in labs where organic solvents were used. 50 compressed gas cylinders exploded in the fires.	9 (5)
Large manufacturing plant, San Fernando Valley	Fire Protection Piping	Fire protection piping failed	1 (3-49)

Location	Category	Description	Ref.
Beverage can facility, Chatsworth	Fire Protection Piping	Numerous leaks in fire sprinkler system	1 (3-49)
Twelve Oaks Lodge 2820 Sycamore La Cresenta	Fire Protection Piping	Broken overhead F.P. piping. New 1" lines and hangers replaced. 3/8 coach screw rods suspending 1" branch lines pulled out of the bottom of the joist. Piping fell and broke at 1'4x1 x 1/2 fitting at threads.	4 (16, I-02)
Department Store, Los Angeles	Fire protection Piping	Fire sprinkler head broke (riser connection) due to interaction with suspended ceiling	1 (5-4, 5-5)
Northridge Fashion Center	Fire protection Piping	Most major department stores suffered interior damage when tiles in unbraced suspended ceilings were dislodged, breaking sprinkler pipes. The result was severe water damage to inventory.	1 (5-4)
Trillium Complex in Warner Center	Fire protection Piping	Broken sprinklers damaged banquet rooms.	1 (5-6)
Olive View Medical Center	Fire protection Piping	Numerous fire sprinkler lines were broken at the connection just above the sprinkler heads.	1 (5-10)
Holy Cross Medical Center	Fire protection Piping	Sprinkler lines throughout the facility had numerous leaks at joints above the discharge heads.	1 (5-11)
Northridge Hospital Medical Center	Fire protection Piping	Considerable damage due to fire sprinkler and domestic water leaks.	1 (5-11)
VONS Store, Northridge Mall	Fire protection Piping	Sprinklers popped. Lots of water damage.	2 (183)
VA Hospital	Fire protection Piping	Rupturing of the sprinkler system caused interior damage.	2 (235)
Anhueser-Busch 15800 Roscoe Blvd. Van Nuys	Fire protection Piping	Approximately 2,200 feet of Schedule 40 steel F.P. pipe (up to 8") fell down off the ceiling. C-clamps were used with no retainer straps. Powder-driven studs were used on sway bracing (3/8" studs into steel beams). Also an issue with longitudinal seismic bracing.	4 (16, I-01)
Panorama Towers 8155 Van Nuys Blvd. Panorama	Fire protection Piping	Underground ductile 6" F.P. piping broke. Backfill not clean (concrete rubble). Underground service cracked because it had been layed on a piece of rubble during original construction. Earth movement created a pressure point on piping causing crack in ductile iron main. Also broken 1-1/2" overhead pipe and fittings.	4 (16, I-03)
Unknown	Fire protection Piping	Upright F.P. sprigs moved downwards. Joints leaking.	4 (16)
Unknown	Fire protection Piping	2" F.P. pipe threads pulled out of coupling. Issues with piping material and depth of threads cut into pipe.	4 (16)
Unknown	Fire protection Piping	Powder-driven studs broke out of concrete on F.P. line.	4 (16)
Unknown	Fire protection Piping	U-bolts pulled off of F.P. line. C-clamps used.	4 (16)

Location	Category	Description	Ref.
Unknown	Fire protection Piping	Broken hangers and broken F.P. line. Issues with lateral and longitudinal seismic bracing, C-clamps, and mechanical fittings.	4 (16)
Unknown	Fire protection Piping	Sway bracing pulled out on F.P. line. Issues with lag bolts and longitudinal seismic bracing.	4 (16)
Gillette Co. (Paper-Mate) 1681 26th St. Santa Monica	Fire protection Piping	Older F.P. system installed with only 4-way used for longitudinal bracing. Fastener / anchors pulled out of brick exterior wall and permitted bulk main to sway and break tee at opposite end of main. Repaired with thru-bolt, washers, etc.	4 (17, I-15)
Gillette Co. (Paper-Mate) 1681 26th St. Santa Monica	Fire protection Piping	Overturning storage rack pulled down overhead F. P. piping which broke off at ceiling lines. Issues with stability of rack storage units, in-rack fire sprinklers, and piping arrangement.	4 (17, I-15)
Unknown	Fire protection Piping	Recessed fire sprinklers needed to be replaced. Solid ceilings (stucco/sheet rock) sheared sprinklers. Ridge piping systems did not move with ceilings.	4 (17)
Unknown	Fire protection Piping	Riser mechanical coupling on F.P. line damaged. 6" and 8" couplings. Issue with tolerance (depth of groove).	4 (17)
Warner Bros. Studios Burbank	Fire protection Piping	Hangers failed on F.P. line. Old system, 1940s. Coach screw rods pulled out of dry "old" wood. Lags pulled out of wood, lags hammered in, not screwed into pilot hole. Issues with lateral and long. seismic bracing.	4 (17, I-52)
Unknown	Fire protection Piping	F.P. sprinklers pulled up through ceiling. Seismic bracing attached to metal decking. Fasteners pulled out. Hangers damaged and broken.	4 (17)
Unknown	Fire protection Piping	F.P. piping material broke at threads. Threadable thinwall piping materials used. Issues also with tolerance (depth of cut threads) and rigidity of material.	4 (17)
Sears North Hollywood	Fire protection Piping	Broken armovers on F.P. line. Caused by movement of large HVAC ducts. Pipe fastened to duct with pipe straps.	4 (17, I-56)
George Rice and Sons 2001 N. Soto St. Los Angeles	Fire protection Piping	Grooved coupling leaking on F.P. line. Rubber gasket bridle (old and hard) used. Also issue with lat. and long. seismic bracing.	4 (18, I-58)
Northridge Hospital 18300 Roscoe Blvd. Northridge	Fire protection Piping	Broken F.P. piping (underground and overhead). Problems with fasteners on seismic bracing (powder-driven studs) and clearance through floors and walls.	4 (18, I-79)
Unknown	Fire protection Piping	Broken pipe hangers on F.P. line. Problems with powder-driven studs.	4 (18)
Unknown	Fire protection Piping	Broken underground F.P. piping. Post indicator valve (PIV) moved.	4 (18)
Unknown	Fire protection Piping	Broken overhead F.P. piping. Problem with long. seismic bracing. Powder-driven studs on fasteners pulled out.	4 (18)

Location	Category	Description	Ref.
Unknown	Fire protection Piping	F.P. sprig up sprinklers rolled. Problem maintaining alignment.	4 (18)
Unknown	Fire protection Piping	Broken overhead F.P. piping. Problem with C-clamps without retaining straps. Issues with lat. and long. seismic bracing.	4 (18)
Arcs Mortgage 26541 Agoura Road Calabasas	Fire protection Piping	Eight broken fire sprinkler heads. Problem with clearance to objects, installed 1/4-1/2" from lower edge of wood beam. Broke off when building shifted. Installation not to code.	4 (18, I-120)
Nordstrom Department Store Topanga Cyn. & Victory Blvd. Canoga Park	Fire protection Piping	Underground control valve on F.P. line broke due to settlement of building. Approx. 75 sprinkler heads broke or out of alignment. Sway bracing was shot to steel beams. Powder-driven fasteners failed.	4 (I-08)
Fox Plaza Avenue of Stars Century City	Fire protection Piping	Three pieces of 1" F.P. line broken at fittings in this parking structure. Approximately 100 3/8" powder driven studs broke out of concrete.	4 (I-11)
Rocketdyne (Bldg. 102) 8900 DeSoto Avenue Canoga Park	Fire protection Piping	Broken F.P. pipe, broken rings, U-bolts pulled off. Bulk mains moved and caused tee / cross fittings to break and water flow resulted in fire pump running; thus emptied on-site water storage tank.	4 (I-12)
General Motors 8000 Van Nuys Blvd. Van Nuys	Fire protection Piping	Leaking mechanical fittings, broken F.P. pipe, broken hangers, U-bolts pulled off.	4 (I-13)
Carpenters Union Hall 15885 Valley View Circle Ct. Sylmar	Fire protection Piping	Broken F.P. pipe, broken rings, sprig-ups rolled, sway bracing pulled out.	4 (I-14)
I Magnum (Magnin ?) 6101 Owens Mouth Woodland Hills	Fire protection Piping	Hangers on F.P. line damaged. C-clamps slid off flanges. Threads leaked.	4 (I-16)
Ragu Foods 5355 Cartwright Avenue North Hollywood	Fire protection Piping	3-1/2" and 4" F.P. main damaged. 1" drops damaged Recessed sprinkler heads needed replacing.	4 (I-28)
Lucky Store 2510 PCH Hermosa Beach	Fire protection Piping	Damaged 6" grooved joint on F.P. line. Sprinkler escutcheons needed replacement.	4 (I-29)
K-Mart 51 E Tierra Rajada Simi Valley	Fire protection Piping	Broken overhead F.P. piping, damaged hangers. Mains, line, drops, hangers had to be replaced and repaired.	4 (I-33)
Sears Northridge Fashion Center Northridge	Fire protection Piping	Broken F.P. piping and fittings. Replaced hangers, heads, EQ bracing and broken grooved coupling at riser. Cast iron rings failed in numerous places. Sprinkler activated.	4 (I-54)

Location	Category	Description	Ref.
Sears Burbank	Fire protection Piping	Broken F.P. piping, added hangers (overspaced or missing). Threadable thinwall piping broken at threads in numerous places. Many EQ braces installed at too severe an angle, allowing pipe to move excessively. C-type clamps slid off flanges.	4 (I-55)
LA Police Credit Union Van Nuys	Fire protection Piping	F.P. pipe hangers attached with tek screws into wood (improper attachment). Hangers and sprinkler head needed replacement.	4 (I-57)
Mervyns 6605 Fallbrook Ave. Canoga Park	Fire protection Piping	Broken F.P. pipe. Broken heads. Sway bracing damaged. Leaks in system. Seismic bracing and hangers broken or damaged.	4 (I-59)
American National Can Co. 20730 Prarie St. Chatsworth	Fire protection Piping	Broken F.P. piping. Broken heads. Hangers broken. Sway braces damaged. Some braces shot with powder-driven pins and attached to walls. C-type clamps slid off flanges. They were provided with retaining straps and locknuts.	4 (I-60)
Fedco Dept. Store 14920 Raymer St. Van Nuys	Fire protection Piping	Broken F.P. piping. Seismic bracing and hangers damaged. Anchors pulled out. System installed in accordance with 25 year old code (3/8" lags and powder-driven pins). C-clamps slid off flanges, no retaining straps, but they did have locknuts.	4 (I-61)
Redken Labs 6625 Variel Canoga Park	Fire protection Piping	Broken F.P. line. Broken cast iron fittings, piping, pipe hangers, EQ bracing, and sprinkler heads. Grooved couplings leaked. C-clamps slid off flanges. No retaining straps, but they did have locknuts. Powder-driven fasteners failed.	4 (I-66)
Media Mall 201 E. Magnolia Burbank	Fire protection Piping	Broken threadable thinwall F.P. pipe and concealed heads (1" line). EQ bracing damaged.	4 (I-67)
Pep Boys 2640 E. 45th St. Vernon	Fire protection Piping	EQ bracing on F.P. line damaged. 1/2" lag bolts 3-1/2" long were pulled out of wood beam in 4 places.	4 (I-69)
Atlantic Optical Pacoima	Fire protection Piping	Gridded F.P. system. Lines jumped and heads busted. Hung by U-hooks. Fasteners / bracing pulled out.	4 (I-71)
Santa Monica Medical Center 2001 Santa Monica Blvd.	Fire protection Piping	Hangers on F.P. line damaged. Powder-driven fasteners on F.P. line pulled out.	4 (I-80)
Hughes Aircraft co. Van Nuys Airport Van Nuys	Fire protection Piping	5" mechanical fitting at top of F.P. riser damaged. Old system.	4 (I-103)
Hollywood Center Sunset Hollywood	Fire protection Piping	1-1/4" threadable thinwall F.P. line severed. Sprinkler heads damaged.	4 (I-106)
Henry Radio Bundy Los Angeles	Fire protection Piping	Sprinkler heads pulled up above plaster ceiling.	4 (I-111)

Location	Category	Description	Ref.
HEXCEL 20701 Nordoff Chatsworth	Fire protection Piping	Sprinkler heads on F.P. lines damaged when system shifted approx. 13" due to EQ. Sway bracing was not installed. 4" crossmain did not have adequate hangers installed. C-clamps slid off flanges. They had locknuts, no retaining straps.	4 (I-114)
Encino Financial 16133 Ventura Blvd. Encino	Fire protection Piping	300 sprigs on F.P. line had to be reset to vertical. Powder driven fasteners failed.	4 (I-117)
St. Johns Hospital Santa Monica	Fire protection Piping	Underground and overhead F.P. lines broken. Fittings, heads and hangers had to be replaced. C-clamps slid off flanges. Powder-driven fasteners failed.	4 (I-119)
Spray Lat 3465 La Cienega Los Angeles	Fire protection Piping	Hangers broken on F.P. line. 40' of 3" main re-hung. Powder-driven fasteners failed.	4 (I-123)
Olive View Hospital	Fire protection Piping	Damage to the sprinkler and chilled water systems made the building unusable.	5 (36)
Holy Cross Hospital	Fire protection Piping	The facility suffered water damage from broken sprinklers and other piping.	5 (36)
Various Fire Protection Systems	Fire protection Piping	Typical damage to fire sprinkler systems included broken pipes due to differential building movement or the sway generated in long pipe runs without adequate bracing. Sprinklers installed in the downward or pendent position from piping above ceilings were in some cases sheared off. In other cases sprinklers installed in drop ceilings were pulled through the ceiling by the upward movement of the pipes and punched new holes in the ceilings during the downward movement. While the punching may not have resulted in leads, it damaged the sprinkler deflectors which generate the desired spray pattern and decrease the sprinkler performance.	5 (160)
Various Wet Pipe Sprinkler Systems	Fire protection Piping	Local increases in pressure caused higher pressures to be "trapped" in sprinkler systems. If not bled off, pressures could lead to premature failure and reduced effectiveness.	5 (160)
Various Tilt-Ups	Fire protection Piping	Common non-structural damage included separation of sprinkler pipe joints and falling of suspended ceilings.	3 (44)
18 Shopping Centers	Fire protection Piping	Survey showed several badly damage by water from broken sprinkler lines. Cause was suspended ceiling movement that impacted sprinkler heads.	3 (59)
Holy Cross Medical Center	Fire protection Piping	Water damage was prominent from sprinklers and other piping.	3 (63)
Pediatric Hospital	Fire protection Piping	Sprinkler failure reported.	3 (66)
Large Manufacturing Facility San Fernando Valley	Fire protection Piping Tanks	Failed fire protection piping. Minor misalignment of production lines, spalling at several tank footings.	3 (75)
Beverage Can Company Chatsworth	Fire protection Piping	Cooling water pipe supports were damaged. Fire sprinkler system had numerous leaks.	3 (75, 76)

Location	Category	Description	Ref.
Electronic Data Processing and Manufacturing Facilities	Fire protection Piping	Uncontrolled leakage of fire sprinkler systems saturated floors.	6 (22)
Various	Fire protection Piping	Several cases of sprinkler system damage due to lack of displacement compatibility between flexible suspended ceilings and rigid fire sprinkler systems. Damage occurred when sprinkler heads punctured through the ceiling tile or when piping broke. Several cases of broken seismic braces for the sprinkler mains were also observed.	6 (26)
Various	Fire protection piping	Very few bldg. had sprinkler piping installed to the 1991 NFPA, so EQ largely tested older versions of the code	9 (4)
High-rise steel frame structures in Warner Center and Woodland Hills	fire protection Piping	Pneumatically installed shot-pins at vertical sprinkler pipe hangers failed, severing the branch lines and causing water damage to floors below.	1 (5-6)
Large storage facility, Chatsworth	Fire Protection Tanks	Unanchored fire tank, slightly smaller than 250,000 gallon tank at adjacent (1/3 mile away) facility suffered elephant's foot buckling.	1 (3-49)
AES Placerita Power Plant, Newhall	Fire protection Tanks	Two fire fighting water storage tanks were damaged and lost content. One is an unanchored bolted steel tank. This tank experienced elephant's foot buckling. The other is a welded steel tank with 2" anchor bolts. The tank wall has stiffening plates at the bolt locations. The bolts deformed, indicating that the tank rocked and rotated significantly. The R/C foundation was damaged by bolt pull-out. Bolts pulled out slightly and twisted. Soil in the surrounding area had cracks of up to 18" wide with a 30" drop in elevation.	2 (93, 105, 106)
Storage Facility Chatsworth	fire protection Tanks	Unanchored fire tank (slightly <250,000 gal) sustained elephant's foot buckling.	3 (76)
Beverage can facility, Chatsworth	Fire Protection Tanks & Piping	A 250,000 gallon unanchored firewater tank experienced elephant's foot buckle. The tank discharge pipe was damaged by tank uplift and the tank lost its contents.	1 (3-49)
Unknown Inter-exchange Carrier (IEC)	Generator	IEC lost service on two of its main electronic switching systems in its office near the epicenter because it could not start a backup generator and had to rely on batteries, which were depleted in about 6 hours.	1 (4-3)
Donald C. Tillman Water Reclamation Plant 600 Woodley Ave. Van Nuys	Generator	1500 kW diesel generator was shut down when operator heard noises. When restarted sparks appeared and emergency system shut down again.	5 (133)
Olive View Medical Center Sylmar	Generator	Emergency power generator come on, but failed when the day tank ran dry and controls did not allow for fuel transfer.	3 (63)
Holy Cross Medical Center	Generator	Radiology services were not available because of the power outage and lack of generator capacity to power radiology equipment and lack of water to develop film. Press accounts attribute one fatality at the hospital to failure of back-up electrical service to supply a patient's life support equipment.	3 (64)

Location	Category	Description	Ref.
Veterans Administration Medical Center, Sepulveda	Generator Control System Power Distribution	The emergency generator components were undamaged but service was not provided because of distribution or control system problems. Patients were evacuated in darkened buildings.	3 (65)
St. John's Hospital Santa Monica	Generator Piping	The emergency generator was shut-down because of breaking of the cooling water line (ran up to the roof and across a separation joint). The cogeneration plant was shut-down when cooling water was lost for the same reason.	3 (65)
Water Reclamation Plants	Generator	At the 80 mgd plant the emergency generator started automatically but the operator shut it down because of concern about its operation.	3 (70)
Various Central Offices	Generator	All CO's experienced power failures and backup generator problems. Overload is the main cause of generator problems.	3 (73)
Hospital in Sylmar	Generator	Bolts between generator and isolator failed. Expansion anchors pulled out.	10 (7-7)
Hospital in Sylmar	Generator	Bolts between generator and isolator failed. Expansion anchors pulled out.	10 (7-7)
Northridge Hospital Medical Center	Generators	One emergency generator failed to start, two functioned normally.	1 (5-11)
LA Fire Department	Generators	Two backup generators failed.	1 (6-5)
Hospitals	Generators	Emergency generators failed at at least one site.	3 (87)
Central Offices	Generators	Loss of off-site power at all COs, and problems with backup power from emergency generators, mostly from overload.	6 (17)
Cal State Northridge	Hazardous materials	Chemical spills occurred at over 200 locations, mostly laboratories	9 (5)
Olive View Hospital	HVAC	Several air handling units on the roof came off their supports.	5 (36)
Northridge Hospital	HVAC	Large fans on the fourth floor roof failed their anchorages and seismic restraints, damaging attached ducting.	7 (36)
Holy Cross Hospital	HVAC	Damage to the air handling system caused closure of the building. A large portion of the facade of the roof-enclosure was detached when it was struck by the damaged fan.	5 (36)
Hospital in Palo Alto	HVAC	Several exhaust fans on isolation springs were thrown of their supports	10 (7-2)
Hospital in Sylmar	HVAC	Expansion anchors failed with concrete spalling	10 (7-7)

Location	Category	Description	Ref.
Valley Generating Station	HVAC Piping, Instrumentation Relays	At about 0.4g the facility sustained cracks in steel struts, a twisted wide flange, distorted exhaust duct insulation panels, damaged piping insulation, inoperable combustion air instruments, leakage in a welded condensate line, and superficial damage to building elements. Numerous relays had to be reset prior to restart.	1 (4-15)
Olive View Medical Center	HVAC	Heating coil connections broke on all floors	1 (5-10)
Olive View Medical Center	HVAC Pumps Fans	In the rooftop HVAC penthouses (2.3g peak acceleration on roof), rod hung pump fittings were damage, fan support anchors failed, and vibration isolation mounts with seismic restraints failed.	1 (5-11)
Holy Cross Medical Center	HVAC	Within HVAC penthouse, fans were dislodged from mountings.	1 (5-11)
Holy Cross Medical Center, San Fernando	HVAC	Ventilation fans displaced through grills in front wall of the roof penthouse.	2 (184, 195)
Various Hospitals	HVAC Piping Fans	Major nonstructural element damage occurred in mechanical penthouse. In several facilities, large in-line supply fans were thrown through the exterior walls of the penthouse.	3 (48)
Olive View Medical Center Sylmar	HVAC	HVAC equipment on the roof or in roof-level penthouses was damaged but not disabling. Failure of seismically resistant (snubbed) spring mounts for largest HVAC unit occurred because of inadequate bolt length attaching equipment chassis to isolator.	3 (63, 64)
Holy Cross Medical Center	HVAC	HVAC service outage was the sole reason the facility could not be returned to service. Suspended fans swung sufficiently to pound against louver panels and knock them out on the penthouse.	3 (63, 64)
Various Central Offices	HVAC Piping Valves	HVAC loss due to power and equipment failure. Damage included broken pipes, damaged valves and crushed or slipped supports.	3 (73)
Valley Generating Station	HVAC	Distorted exhaust duct insulation panels.	3 (76)
Central Offices	HVAC Piping Compressors Chillers	Failure of HVAC systems in penthouses, including broken piping, failed pipe supports, and shifted chillers and compressors. Contributors include amplified building motions, use of non-seismic vibration isolators, and poor bracing of piping.	6 (17)
Various	HVAC	Seismically snubbed, spring-supported air handling units supported on the roofs of two ad three story buildings were thrown free from their supports.	6 (27)
Holy Cross Medical Center	HVAC Ducting	A HVAC duct which crossed a building seismic joint without an expansion joint was torn apart.	1 (5-11)
Valley Generating Station	Instruments	Inoperable combustion air instruments.	3 (76)

Location	Category	Description	Ref.
Substations	Insulators	At a number of substations insulators broke at the base, while the metal support structure was undamaged.	1 (8-7)
Various large retail stores	Light tubes	In large retail stores of approximately 50,000 sq. ft. where clip-on type open tube fixtures are utilized, light tube falls occurred (about 10-15%).	1 (5-2)
LEVITZ, Northridge Fashion Mall	Lights	Strip lights (fluorescent fixtures) fell to floor.	2 (184, 192)
Olive View Medical Center	Lights	Safety wires were effective where the ceiling displaced sufficiently, or the light fixtures moved from their own inertial forces, to dislodge and "fall" a few inches.	3 (59)
LA Public Library Northridge Branch	Lights HVAC	Lights and diffusers fell from the ceiling.	3 (61)
Olive View Medical Center Sylmar	Lights	Numerous light fixtures had popped from ceiling grid mounts, but almost all dangled rather than fell because of two diagonally-opposite safety wires.	3 (63)
Olive View Medical Center Sylmar	Lights	Flange-clamp connections of bracing cables for suspended lights in mechanical areas failed.	3 (63, 64)
Various Schools	Lights	Approximately 100 classrooms had one or more lights fixtures fall to the floor or on top of desks. These are the pendant mounted light fixture, installed before safety wires were required. They weight up to 80 lbs, with metal parts with relatively sharp edges.	3 (65)
LA County Fire Command and Control Facility	Lights	A small amount of distress occurred at the tops of pendant light fixture connections, and the lights were observed to sway noticeably in the EQ.	3 (66)
Various	Lights	Ceiling damage resulted in broken light fixtures.	6 (26)
Large Warehouses and Manufacturing Plants	Lights	Long rows of suspended light fixtures hung by chains were free to swing vertically and horizontally, causing fixture damage. In some cases, chain mounted light fixtures fell 30-40'.	6 (26)
Various	Mechanical Equipment	Roof mounted equipment infrequently were damaged, especially those items mounted on vibration-isolators.	7 (34)
Various	Non-structural	There were about 40 buildings with major non-structural damage for every building with severe structural damage. Based on data from 100,000 bldg.	9 (3)
Beverage can facility, Chatsworth	Ovens	Large ovens pulled anchors and shifted one to two inches	1 (3-49)
Large manufacturing plant, San Fernando Valley	Piping	Minor misalignment of production lines	1 (3-49)
Beverage can facility, Chatsworth	Piping	Cooling water pipe supports were damaged	1 (3-49)
Van Norman Pumping Station	Piping	54" discharge line damaged	1 (4-3, 4-4)

Location	Category	Description	Ref.
Burbank Power Plant	Piping Tanks Crane	Broken PVC line, spalling at tank footings, failure of small diameter pipes, deformation of tank anchor clips, and damage (not failure) to a crane.	1 (4-15)
Aliso Canyon Gas Storage Facility	Piping Fin fans	Deformation of above-ground pipe supports, displacement of runs of injection and withdrawal lines, and structural damage to a fin fan unit.	1 (4-16)
Aliso Canyon Gas Storage Facility	Piping	Break in 10", 200 psi line, ruptured by landslide movement at an overbend.	1 (4-16)
Aliso Canyon Gas Storage Facility	Piping	Landslide undermined an injection line near the top of the slope. Debris from the slide caused deformation of two withdrawal lines and an injection line.	1 (4-18, 4-19)
Aliso Canyon Gas Storage Facility	Piping	Leaking flange in area of slope movement. Otherwise no leaks or ruptures of above ground withdrawal and injection pipelines.	1 (4-18)
Honor Ranch Storage Facility, near Newhall	Piping Tanks Transformers	Disruption of the fire loop system, brine filtration equipment, and access roads. A 16" water main, water tank, gas piping, and electrical transformer also were damaged.	1 (4-21)
Four Corners Pipeline, various locations	Piping	10" oil pipeline, built in 1926 with oxy-acetylene welded joints,suffered eight breaks at girth welds. Damage near Placeritas pumping station due to permanent ground deformation.	1 (4-24)
Hughes Aircraft and Rocketdyne, Canoga Park	Piping	Broken water pipes shut down facilities.	1 (5-6)
Lockheed Burbank	Piping	Broken water pipes shut down facilities.	1 (5-6)
Olive View Medical Center	Piping	Two chilled water lines broke in the roof penthouses.	1 (5-10)
Holy Cross Medical Center	Piping	Potable and non-potable water supply had to be turned off due to leaks.	1 (5-11)
Holy Cross Medical Center	Piping	Within the HVAC penthouse a chilled water line broke, flooding the floors below.	1 (5-11)
Northridge Hospital Medical Center	Piping	Gas and water (potable and non-potable) turned off due to leaks.	1 (5-11)
AES Placerita Power Plant, Newhall	Piping	Extensive damage to pipes due to shifting and rocking movement of heavy equipment and vibrations of the connecting pipes themselves. Many pipes fractured and broke off and fell from their supports.	2 (93)
Granada Hills Community Hospital, Balboa Avenue, Northridge	Piping Heating	Hospital continued to operate despite loss of water and heat. Emergency care center was established in the parking lot.	5 (37)
Water System	Piping	Following the EQ, pressure in the water system dropped due to disruptions in supply and more than 3000 leaks.	5 (152)

Location	Category	Description	Ref.
Unknown	Piping	One major above-ground gas pipeline was damaged by a rockslide.	3 (19)
LADWP Van Norman Complex San Fernando	Piping	Differential settlement of the ground w.r.t. structures of up to 8", where chlorine lines were severed. Rigid PVC piping supplying an overflow tank ruptured, rendering the plant inoperable.	3 (25, 26)
Lower San Fernando Dam	Piping	There was a major rupture of a 73" riveted steel pipe where it exited the downstream side of the right abutment. Because the broken pipe caused a severe washout of the area, it could not be determined if the break was caused by ground movement.	3 (26)
Upper San Fernando Dam	Piping	Near the foot of the embankment, an approx. 3' pipe suffered major damage. The pipe was supported above ground on piers. Gaps of up to 4" were observed around some piers, indicating lateral movement. There was lateral spreading of the slope. At some of the supports, the mounting columns completely failed and the pipeline dropped onto the piers. At others the mounting columns buckled, but remained attached.	3 (26)
Kings Harbor, Redondo Beach	Piping	An 8" water main ruptured, flooding the entire area. It occurred in an area of liquefaction.	3 (28)
Various Hospitals	Piping Generators Elevators	Along with water leakage, emergency power service was unreliable and elevator outages occurred even in some recently constructed facilities.	3 (56)
Olive View Medical Center Sylmar	Piping Ceilings	The hospital had to evacuate all of its patients because of breakage of both sprinkler and chilled water lines. In one location a pipe ruptured completely at the threaded elbow joint of drop to the run. Damage was probably caused by differential motion within ceiling plenum, because the ceiling didn't displace significantly here. Slight dropping of lay-in fixtures, with safety wires preventing complete falling, was common.	3 (62, 63)
Indian Hills Medical Center, Sylmar	Piping Ceilings	Water damage occurred. Also ceiling damage, and fallen diffusers etc. from ceilings.	3 (64)
Veterans Administration Medical Center, Sepulveda	Piping	Water damage from broken pipes was extensive enough in two buildings to cause evacuation.	3 (65)
St. John's Hospital Santa Monica	Piping	Water damage was caused by both drain and supply line breakage.	3 (65)
Water System	Piping	All four pipelines from No. CA to Santa Clarita and San Fernando Valleys and 3 water treatment plants were broken (54"-120" steel pipes).	3 (69)
Water Treatment Facilities	Piping	Treatment plants (25, 550, and 600 mg/day had settlement around plants, leaks at construction joints, leaks in plastic chlorine solution line, and damage to wooden baffles in the basins.	3 (69)
Water Reclamation Plants	Piping Equipment Ceilings	Typical damage included dislodged sludge scrapers, broken auxiliary piping, and fallen ceiling tiles.	3 (70)

Location	Category	Description	Ref.
Aliso Canyon Gas Storage Field Santa Susana Mountains N of Granada Hills	Piping	10" gas line broke. Damage to above ground pipe supports. Displacement of runs of injection and withdrawal gas lines.	3 (71)
Santa Clara River Santa Clarita Valley	Piping	A 10" line had a leak in a cracked weld. It had a half dozen other leaks, principally in welds, at other locations along the pipeline.	3 (72)
Valley Generating Station	Piping	Damaged piping insulation. Leakage in a welded condensate line.	3 (76)
Burbank Power Plant	Piping	Broken PVC line. Failure of small diameter pipes.	3 (77)
Glendale Power Plant	Piping	Rupture of 24" cooling tower inlet risers	3 (77)
Various Airports	Piping Ceilings	Water pipe joint leaks and fallen ceiling tiles reported.	3 (85)
Unknown Hospital	Piping	Ruptured water lines inundated the upper floors of a 380 bed hospital, forcing its evacuation.	3 (87)
Kern County to South Bay Refinery	Piping	A crude oil pipeline running from the Kern County Oil Fields to a refinery in the south Bay broke in eight places. At one break 40,000 gallons spilled down a Pacoima street and caught fire. Another break emptied into a storm drain and dumped 150,000 gallons into the Santa Clara River.	3 (96)
Water and Gas Systems	Piping	Breaks occurred in 54", 77", 84", and 120" water lines. Large diameter welded steel water and gas pipelines failed in tension on one end and compression on the other end of a 1000' block of soil that moved longitudinally down Balboa Boulevard.	6 (13)
Jensen Water Treatment Plant	Piping	One of two 84" welded steel water feeder lines cracked at a bell from longitudinal movement.	6 (13)
Castaic Lake Water Agency Water Treatment Plant	Piping	The 54" primary treated water transmission line feeding the Santa Clarita Valley had a failure rate of one break per mile (four breaks). The pipeline is made of reinforced concrete. Welded joints failed as bells cracked. Bell and spigot joints separated.	6 (13, 16)
Van Nuys Water Reclamation Plant	Piping	Pipe Break	6 (15)
Glendale Water Reclamation Plant	Piping	Pipe Break	6 (15)
Various	Piping	Free standing pipe supports on roofs collapsed in several cases primarily because they were attached to the roof surface by only a roofing compound.	6 (27)
Northridge Hospital	Piping	Piping in the hospital's emergency power plant failed at bolted elbow connections due to large inertial forces and lack of restraint.	7 (36)
Olive View Hospital	Piping	At least two piping runs on the roof failed because of inadequate bracing.	7 (37)

Location	Category	Description	Ref.
LA Aqueduct Filtration Plant	Piping	Several PVC chlorine lines fractured due to inadequate bracing.	7 53
Jensen Water Treatment Plant	Piping	85 in welded steel supply line cracked on the curved portion of a long bell.	8 (3)
LA Aqueduct No. 1	Piping	Aqueduct was damaged at four locations. Concrete channel was fractured at many locations. Cast-in-place concrete siphons were shattered at two locations.	8 (4)
LA Aqueduct No. 2	Piping	2 mechanical couplings were pulled apart; a split occurred in an 8 in long steel wye branch stiffener; circumferential tear in the top of a buried 77 in welded line;	8 (4)
Castaic Conduit	Piping	Main line from the Castaic reservoir had to have 35 leaks repaired in the 54, 39, and 33 in concrete lines. Breaks occurred at welded fabricated bends and one long horizontal reaches where rubber joints pulled apart.	8 (6)
Simi Valley	Piping	78 inch North Branch Feeder had 15 to 20 major pulled joints and 500 cracks requiring repair.	8 (6)
Sangus Water Reclamation Plant	Piping	21 inch steel process air pipe was damaged	8 (14)
Hospital in Sylmar	Piping	Roof drains separated from drain lines	10 (7-7)
Unknown	Piping, Tanks	Anchorage failure of process tanks led to excessive piping loads and failure of flanged piping	1 (3-47, 3-48)
Substations	Porcelain insulators	Damage to brittle porcelain insulators was the primary contributor to power outages.	1 (4-11)
LA Fire Department	Power	The LAFD lost its computer-aided dispatch capability because of a malfunction of backup power supplies.	3 (94)
Unknown Industrial Facility	Pumps	A pump located in the penthouse of a building that sustained structural damage, was heavily damaged.	3 (74)
Department Store Sherman Oaks	Pumps	Failed base connections on two pumps due to inadequate bracing	7 (21)
Holy Cross Medical Center	Radio Antenna	Radio communications unavailable after earthquake due to failure of a roof mounted antenna.	1 (5-11)
Valley Generating Station	Relays	Numerous relays had to be reset.	3 (76)
LADWP	Reservoirs	Many reservoirs were drained as a result of breaks or leaks in the distribution system	7 (54)

Location	Category	Description	Ref.
Unknown manufacturing plant	Shelves Storage Cabinets	Specialized carbide tooling stored on shelving was thrown to the floor resulting in chips in brittle tooling material and mars in tooling surfaces	1 (5-11)
55,000 sq. ft. warehouse, Santa Monica	Storage Rack	Pallet racks failed. Initiated in column base plate welds in two multi-bay rows which toppled over and knocked out 40% of the racks. Welds between cold formed steel posts and 3/16" thick base plates unzipped, leaving 1/2" anchor bolts intact.	1 (5-7, 5-9, 5-10)
Unknown	Storage Rack	5000 sq. meter tilt-up warehouse barely withstood failure of interior storage racks. Many bracing members in the racks had buckled. Racks were loaded to about 60% of design.	7 (44)
Levitz Northridge Fashion Center	Storage Racks	Storage racks failed in the longitudinal (rod cross-braced) direction.	3 (61)
UCLA Library	Storage Racks	There were failures in older shelves with X-rod longitudinal bracing, where books were not ejected.	3 (61)
Home Depot	Storage Racks	Approximately 10% of the racks in various home depot stores collapsed, all heavily loaded with boxes of tile or sacks of cement.	3 (61)
Home Base 8341 Canoga Avenue	Storage Racks	Store used racks, but without pallets. A rack containing tile collapsed.	3 (61)
Electronic Data Processing and Manufacturing Facilities	Storage Racks	Tall slender tape storage racks that were not anchored tipped over and dumped reels of tape or cartridges onto the floor. Tall storage cabinets often used for data files as well as supplies in computer rooms tipped and fell on other equipment.	6 (23)
Various	Storage Racks	Wall cabinets anchored in drywall were pulled out. Where shelves were not anchored to walls or properly braced, they overturned and spilled contents. In warehouses, partial collapse of pallet racks occurred due to excessive deflection of racks longitudinally.	6 (26)
Various	Storage Racks	"Many unanchored or poorly anchored racks collapsed, causing damage to both contents and buildings from impact."	7 (44)
LEVITZ, Northridge Fashion Mall	Storage racks	Large furniture racking failed in longitudinal direction. Failure of rod cross braces and their connections.	2 (184, 194)
Sylmar	Substation	Most of the $25M damage at Sylmar west was related to failure of ceramic components in insulators.	2 (91)
Electrical substation adjacent to Levitz	Substation Equipment	Drop type concrete anchors failed in tension.	2 (182, 184, 194, 195)
Sylmar, Pardee, Vincent, Rinaldi, RS-J, RS-U, and RS-E substations.	Substation Equipment	Significant damage at these substations. Damage to DC equipment at Sylmar. Damage to porcelain components was typical. all of the live tank 230 kV circuit breakers were damaged at Pardee. All 230 kV dead tank circuit breakers were undamaged at Pardee. Most of the 230 kV circuit switchers were damaged. Most capacitor banks were undamaged.	3 (67-69)

Location	Category	Description	Ref.
Sylmar, Pardee, Vincent, Rinaldi, RS-J, RS-U, and RS-E substations.	Substation Equipment	Damage was generally concentrated in porcelain components in 230 kV and 500 kV equipment, although there was damage in lower voltage classifications. Affected equipment included transformer bushings, live tank circuit breakers, lightning arresters, disconnect switches, rigid busses, coupling capacitor voltage transformers (CCTV's), capacitor banks, circuit switches and a 34.5 kV bus. Dead tank circuit breakers and bulk oil circuit breakers performed well, with no significant damage.	3 (68)
Substations	Substation Equipment	Electrical distribution substations were disrupted due to breakage of fragile components, leading to widespread loss of power for up to two weeks.	6 (1)
Substations	Substation Equipment	Substation damage occurred chiefly in porcelain and other vulnerable components (transformer bushings, live tank circuit breakers, disconnect switches, and so forth).	6 (13)
Sylmar, Pardee, and Rinaldi high voltage substations	Substation equipment	Damage to DC equipment led to power outages. Most of the 230 kV circuit switchers at Sylmar were damaged. Capacitor banks performed well, whereas most were damaged in 1971. Porcelain elements of equipment of 230 kV and 500 kV suffered the most damage.	5 (143-145, 149)
Industrial Manufacturing Plant	Switch Panel	A large electrical switch panel was suspended from an elevated platform hung from the underside of the roof by four pipe columns and a set of braces. One of the pipe columns was 3' long and the others 10' long. The short column failed, leading to partial collapse of the platform and switch panel. Conduit from the top of the switch panel and chilled water lines were trapeze supported. They held up the panel until the chilled water line ruptured and flooded the floor. Then other conduit and trapeze supports carried the load.	6 (24)
Various Telephone Facilities	Switching Transmission Equipment Cable Trays	Buckled hanger rods, buckled and bent auxiliary bars, bent cable trays, pounding of bars against side-walls and loose friction clips did not affect function. There were also loose bolts, slid-out floor shims, localized indentations of cabinet frames, etc. caused by buckled floors; they didn't affect CO operation.	3 (72)
Aliso Canyon	Tank	An older oil tank failed and collapsed. A dike contained the spill.	6 (17)
Large manufacturing plant, San Fernando Valley	Tanks	Spalling at several tank footings	1 (3-49)
Beverage can facility, Chatsworth	Tanks Piping	Anchored waste oil tank (10,000 gallons) pulled its anchors and shifted, breaking the discharge pipe and emptying contents	1 (3-49)
160,000 sq. ft. industrial facility, Chatsworth	Tanks	Overturned tanks	1 (3-49)
110 MW combined plant cycle cogeneration facility	Tanks	Several large storage tanks and smaller tanks associated with the water treatment facility were damaged. Older bolted tanks pulled anchor bolts and leaked at seams. Newer tanks sustained minor pulling of anchor bolts. Tank displacements resulted in failures of attached lines.	1 (3-50, 3-51)
Santa Clarita Valley	Tanks	Sloshing and suction damage to top of welded water storage tank. Internal roof trusses of the tank collapsed.	1 (4-7)
Santa Clarita Valley	Tanks	Elephant's foot buckling of water storage tank.	1 (4-7)

Location	Category	Description	Ref.
Santa Clarita Valley	Tanks	Damaged welded water storage tank. Rocking of tank caused elephant's foot buckling at the tank base and damaged inlet and outlet lines.	1 (4-8)
Santa Clarita Valley	Tanks	Collapsed bolted water storage tank.	1 (4-8)
Aliso Canyon Gas Storage Facility	Tanks Piping	Three water tanks damaged. Pipelines conveying water from main supply tank developed leaks. 5 of 12 oil storage tanks damaged. One collapsed and another sustained a split seam. Other damage consisted of buckling and warping of steel plates.	1 (4-16, 4-18)
Olive View Medical Center	Tanks	A bulk oxygen tank sheared its anchorage and nearly toppled, being caught by a nearby fence.	1 (5-11)
Holy Cross Medical Center	Tanks	Bulk oxygen tanks overturned.	1 (5-11)
Grenada Hills Community Hospital	Tanks	A water tank on the roof failed and flooded the upper floors of the facility	1 (5-11)
Various	Tanks	There were cases where the piping or valves broke due to differential movement between the tank and the piping	1 (8-5)
City of Valencia	Tanks	Extensive damage to 7 steel drinking water tanks in the water district of the City of Valencia and surrounding area.	2 (90)
Larwin	Tanks	Roof damaged due to impact from sloshing water. Anchorage failed (straps welded to tank wall), permanent uplift of 5" on tension side. Elephant's foot buckling. Anchor straps torn off from tank wall, rendering tank as unanchored at the base. Substantial damage to ring foundation. Ruptured piping connected to tank.	2 (90, 96-99)
Magic Mountain	Tanks	Total collapse of bolted tank. Initiated by rupture of steel plate near the base of the tank. Two other tanks, one welded, one bolted, damaged with diamond buckling. Roof a a water tank at nearby site damaged due to sloshing.	2 (90, 100, 101)
AES Placerita Power Plant, Newhall	Tanks	Two 113,500 liter welded steel tanks, shifted 4". Tanks were anchored by 2" anchors. Both tanks now tilt due to permanent differential settlement of 4".	2 (93, 104)
AES Placerita Power Plant, Newhall	Tanks	An anchor bolt for the skid of a hot water tank sheared off.	2 (94, 107)
AES Placerita Power Plant, Newhall	Tanks	A number of small oil tanks were damaged. Liquid fuel sloshed over the top rim of one tank. Fracture of the bottom plate due to elephant's foot buckling caused lost content of another, with the spill contained by a retaining wall. A third tank had diamond buckling at the middle of its bottom course.	2 (108, 109)
Holy Cross Medical Center, San Fernando	Tanks	Liquid oxygen tank slid off concrete foundation (raised pad).	2 (184, 196, 197)
Mulholland Drive and Beverly Glen Blvd.	Tanks	A DWP water reservoir tank suffered damage and emptied during the EQ. The foundation had settled about 6" on the northern side or down-dip, and about 1-2" on the southern side. There were many cracks showing recent movement around the tank area and in various side streets.	3 (30)

Location	Category	Description	Ref.
Olive View Medical Center Sylmar	Tanks	Leg welds on the large oxygen tank failed.	3 (63)
Hospitals	Tanks	Failure or partial failure of large vertically oriented oxygen tanks at hospitals appears to be a common pattern.	3 (63)
Granada Hills Community Hospital	Tanks	Water up to 2' deep was reported at some locations in the hospital. The domestic water supply tank on the roof failed.	3 (63)
Holy Cross Medical Center	Tanks	Damage to a large oxygen tank at its base required rapid installation of a new unit and removal of the old one.	3 (64)
Pumping Facilities and Wells	Tanks Piping	Damage to tanks included rupture of inlet-outlet piping, elephant's foot buckling, shell buckling, ground settlement, and roof damage.	3 (70)
Valencia	Tanks	Contents were lost at an 800,000 gallon water tank after the piping ruptured. The tank also suffered roof damage and elephant's foot buckling.	3 (70, 71)
Oil Pumping Site	Tanks	Severe damage to oil tanks. Contents escaped but were retained by dykes.	3 (72)
Beverage Can Company Chatsworth	Tanks	Anchored waste oil tank (10,000 gal) pulled its anchors and shifted, breaking the discharge pipe and emptying its contents.	3 (76)
Beverage Can Company Chatsworth	Tanks	A 250,000 gal unanchored fire water tank experienced elephant's foot buckling. The discharge line was damaged by uplift and the tank lost its contents.	3 (76)
160,000 sq ft Industrial Facility Chatsworth	Tanks Equipment	Moderate damage to older equipment, including equipment anchorage failures and overturned tanks.	3 (76)
Burbank Power Plant	Tanks	Spalling at tank footings. Deformation of tank anchor clips.	3 (77)
Large Psychiatric Hospital	Tanks	Failure of a rooftop water tank forced the evacuation of a large psychiatric hospital.	3 (87)
Los Angeles (Van Norman) Reservoir Complex	Tanks Piping	Several pipelines and water tanks sheared off their foundations.	6 (9)
Various	Tanks	Older , more vulnerable oil and water tanks experienced damage in the form of elephant's foot buckling, inlet / outlet piping damage, shell buckling, ground settlement, and roof damage from sloshing.	6 (17)
Van Nuys Wastewater Reclamation Plant	Tanks	Leaking expansion joint in a tank near an underground gallery.	6 (17)
Large Manufacturing Facility	Tanks	A large deionized water storage tank (Fiberglass tank) pulled its anchor bolts and tipped over, rupturing the bottom of the tank. The backwash from the ruptured tank blew out the adjacent wall.	6 (23)
Near Northridge Fashion Center	Tanks	Compression failure of 250,000 gallon fire water tank. Tank apparently uplifted about 30 cm and failed attached piping.	7 (43)

Location	Category	Description	Ref.
Near Northridge Fashion Center	Tanks	Anchored 15,000 gallon steel tank stretched its anchor bolts, causing rupture of attached PVC piping.	7 (44)
LADWP	Tanks	Nine above-ground steel tanks (.5- to 2.5-million gallon) failed from: tearing and buckling at base; collapse of roof.	7 (54)
USC Med Center	Tanks	(3) 7500 gal roof mounted tank leaked due to failures in attached piping. Damage from leakage and other non-structural damage led to bldg. closure	8 (10)
Various	Tanks	About 40 water tanks rendered non-functional by the earthquake. Most not AWWA D-100 designs, many were bolted construction, and many were relatively small.. Principal failure modes were damage to inlet-outlet piping, and roof damage.	8 (10)
Valencia Water Reclamation Plant	Tanks	Aluminum covers on all primary sedimentation tanks were bent.	8 (14)
Sangus Water Reclamation Plant	Tanks	The following concrete tanks were damaged: primary and secondary sedimentation ; chlorine contact; filter gallery; aeration.	8 (14)
Various	Tanks	Welded steel tanks constructed to AWWA D-100 and Concrete tanks constructed to AWWA D-110 performed very well.	8 (17)
Hospital in Sylmar	Tanks	Expansion anchors at steel saddle supports pulled out	10 (7-7)
Hospital in Sylmar	Tanks	Bolts anchoring vertical oxygen tank sheared off	10 (7-7)
Central Offices	Telecommunication Cable Trays	Typical damage included bent cable trays, buckled raceway hanger rods, buckled and bent auxiliary bars and bars pounding against walls, loose friction clamps, loosened bolts and slide-out floor shims, and dented cabinets and bent framed from buckled floors.	6 (17)
Central Offices	Telecommunication Equipment	Common problems included malfunction of circuit board cards and unseating of cards from connectors.	6 (17)
Sylmar	Transformer	One spare 500/230 kV DC to AC transformer failed because of busing problem, releasing some mineral transformer oil, causing some environmental problem.	2 (91)
Aliso Canyon Gas Storage Facility	Transformers	A number of transformers fell from poles, disrupting electrical service.	1 (4-16)
Rinaldi	Transformers	12 of 15 single phase 500/230 kV transformers were damaged. Differential settlements of up to 6" at one corner relative to opposite corner were reported at the bases of the damaged transformers.	2 (92)
High voltage transmission stations	Transmission equipment	Near field stations experienced damage to porcelain supported power apparatus, such as circuit breakers, disconnect switches, lighting arresters, rigid bus, capacitor banks, and transformer bushings. Stations farther from the epicenter sustained damage to live tank circuit breakers , disconnect switches supported by tall slender porcelain insulators.	1 (4-13)
Unknown	Transmission Towers	At least two transmission towers collapsed as a direct result of rockslides.	3 (19)

Location	Category	Description	Ref.
Power System	Transmission Towers	Several transmission towers had significant damage with some collapses. Collapsed towers included bolted lattice structures carrying 66 kV and 230 kV. Most had foundation distress and were located near ridge tops.	3 (67)
Transmission System	Transmission Towers	Bolted lattice and other electrical transmission towers suffered damage and some collapses. The towers supported 66 kV, 115 kV and 230 kV lines. Contributory factors included foundation problems and ridge top topographic effects. One bolted lattice steel tower collapsed when the ridge shattered. The tower supported 66 kV lines and pulled down 4 other towers when it fell.	6 (13)
Transmission System	Transmission Towers	A 2-column steel moment frame transmission tower supporting 230 kV lines had the base of one of the columns fracture and the foundation the other uplift. Liquefaction may have contributed to the foundation failure.	6 (13)
230 and 500 kV transmission systems	Transmission towers	Several towers failed. Foundation distress was observed at most of the failed towers.	1 (4-12)
LADWP Transmission System	Transmission towers	Lines coming into the city from the north were down because foundations under two towers failed.	1 (7-5)
Power Transmission System	Transmission towers	Some transmission towers suffered significant damage, many as a result of foundation failure.	5 (143, 149)
Glendale Power Plant	Turbine / Generator	Bearing damage from loss of lube oil	3 (77)
AES Placerita Power Plant, Newhall	Turbines	Shear keys at the base of the turbine foundation were damaged due to vibrational movements of the turbine generators during the earthquake. Concrete next to the shear keys was crushed.	2 (92, 103)
Glendale Power Plant	Turbines (?) Piping	Damage and failures included bearing damage due to loss of lube oil, rupture of two 24" cooling tower inlet risers, and superficial damage.	1 (4-15)
Olive View Medical Center	UPS	The UPS for the hospital computer system functioned for awhile after the earthquake, but then the voltage and frequency of the output became erratic and the system failed.	1 (5-11)
Great Western Bank Northridge	UPS	The UPS functioned until one of the doors that had been inadvertently left unlatched swung open and closed, causing the system to short out. This caused the system to shut down.	6 (23)
Various	Valves	Seismic gas shut-off valves. Survey of over 250 owners found most if not all tripped in San Fernando Valley, Santa Monica, West LA, Beverly Hills, Burbank, Glendale, and other adjacent locations. None reported any leaks, only trips.	3 (72)
Various	Valves	Many air and vacuum valves toppled, had cracked bodies, or damaged floats.	8 (20)
Hospital in Sylmar	Valves	Control valves cracked through cast iron flanges in 2/7 locations	10 (7-7)

Appendix B

Literature Search:
Damage from Earthquakes
Occurring Between 1987 - 1991

References Used in Literature Search for Earthquakes 1987-1991

1. EQE Engineering. April 1990. "The October 17, 1989 Loma Prieta Earthquake: Effects on Selected Power and Industrial Facilities." EPRI report. San Francisco, CA.

2. Rossi, David. December 19, 1990. Telephone conversation with Richard Bradley (head electrician for Marley Roof Tile).

3. Valdez, R., Head Maintenance Man, Watsonville Community Hospital. December 12, 1990. Interview by EQE Incorporated.

4. EERI. May 1990. "Loma Prieta Earthquake Reconnaissance Report." *Earthquake Spectra*, supplement to Vol.6.

5. EERI. May 1988. "The 1987 Whittier Narrows Earthquake." *Earthquake Spectra*, 4 (2).

6. "Summary of Risks to Computer Support Equipment in Central Plant and Main Building." Table A-4. Report on CALFED building response to the Whittier earthquake.

7. EQE Engineering. March 1990. "The October 1, 1987 Whittier Earthquake: Effects on Selected Power, Industrial, and Commercial Facilities." EPRI report. San Francisco, CA.

8. EQE Engineering Inc. 1987. "Summary of the October 1, 1987 Whittier California Earthquake - an EQE Quick Look Report." San Francisco, CA.

9. H.J. Degenkolb Assoc. Engineers. "The Whittier Narrows Earthquake October 1, 1987."

10. McCormick, D. L. Field notes compiled on the Whittier Narrows earthquake.

11. EERI. November 1989. "Lifeline Response to the Tejon Ranch Earthquake." Earthquake Spectra 5 (4).

12. EQE Engineering Inc. "Summary of the June 10, 1988 Gorman California Earthquake." San Francisco, CA.

13. EQE Engineering Inc. "Summary of the June 12, 1988 Alum Rock Earthquake." San Francisco, CA.

14. EQE Engineering Inc. 1988. "The Superstition Hills Earthquake of November 23 and 24, 1987 - an EQE Summary Report." San Francisco, CA.

15. EERI. "Superstition Hills Earthquakes - November 23 and 24, 1987, Imperial County, California." Oakland, CA.

16. EQE Engineering Inc. December 1988. "The Saguenay, Quebec Earthquake of November 25, 1988 - A Preliminary Summary." San Francisco, CA.

17. EQE Engineering Inc. August 1990. "The July 16, 1990 Philippines Earthquake - A Quick Look Report." San Francisco, CA.

18. Munich Reinsurance Company of Australia Limited. "The Newcastle Earthquake '89 - Backgrounds, Causes, Effects, Implications."

19. EQE Engineering Inc. "The December 28, 1989 Newcastle Earthquake." San Francisco, CA.

20. EERI. "The Luzon, Philippines Earthquake of July 16, 1990." Oakland, CA.

21. EQE Engineering Inc. "The April 22, 1991 Valle de la Estrella Costa Rica Earthquake - A Quick Look Report." San Francisco, CA.

22. Wang, L.R.L., C.E. Taylor, and L.V. Lund. August 1989. "Damage Report on Water Lifeline Systems from the October, 1987 Whittier Narrows Earthquake." Technical Report No. ODU LEE-04. Old Dominion University, Department of Civil Engineering.

23. Kennedy/Jenks/Chilton. December 1990. "1989 Loma Prieta Earthquake Damage Evaluation of Water and Wastewater Treatment Facility Nonstructural Tank Elements." National Science Foundation report.

24. National Research Council Canada, Institute for Research in Construction. May 1990. "The 1989 Loma Prieta (San Francisco Area) Earthquake: Site Visit Report." Internal Report No.594.

25. Dames and Moore. 1989. "The October 17, 1989 Loma Prieta Earthquake." Special Report.

26. Structural Engineers Assoc. of California. Ad Hoc Earthquake Reconnaissance Committee. April 1, 1991. "Reflections on the Loma Prieta Earthquake October 17, 1989."

27. EQE Engineering Inc. October 1989. "The October 17, 1989 Loma Prieta Earthquake." EQE Quick Report. San Francisco, CA.

28. Matsuda, E. November 2, 1989. Facsimile to B. Kassawara.

29. Schiff, A. February 20, 1990. Facsimile to McCool.

30. McCool, S., PG&E. December 6, 1989. Interview by EQE Incorporated.

31. Douglas, B., San Mateo Substation Manager, PG&E. Date unknown. Interview by EQE Incorporated.

32. U.S. Department of the Interior. October 1987. "Preliminary Evaluation of Structures: Whittier Narrows Earthquake of October 1, 1987." Geological Survey, Open-File Report 87-621.

33. Isenberg, J., M.T. Phipps, and C. Scawthorn. October 1990. "Watsonville Regional Study: Interaction Among Damaged Lifelines." "Putting the Pieces Together" Proceedings by the Bay Area Regional Earthquake Preparedness Project (BAREPP).

34. EERI. August 1989. "Armenian Earthquake Reconnaissance Report." *Earthquake Spectra.* Special Supplement.

35. Niazi, M., and Y. Bozorgnia. "The 1990 Manjil, Iran Earthquake: Geology & Seismology Overview, PGA Attenuation and Observed Damage." Berkeley Geophysical Consultants and EQE Engineering, Inc. Unpublished report.

36. Astaneh, A., and G. Ashtiany. "The Manjil, Iran Earthquake of June 21, 1990." *EERI Special Earthquake* Report. Oakland, CA.

37. "A Reconnaissance Report on the Iran Earthquake." January 1991. *NCEER Bulletin* 5 (1). NCEER Technical Report No. 90-0017.

38. Boutacoff, D. June 1989. "Real World Lessons in Seismic Safety." *Electric Power Research Institute* (EPRI) Journal.

39. EQE Engineering Inc. 1989. "The December 7, 1988 Armenian USSR Earthquake - An EQE Summary Report." San Francisco, CA.

40. Khater, M., et al. September 1990. "Lifelines Performance During the October 17, 1989 Loma Prieta Earthquake." Proceedings of the 22nd joint meeting of the U.S.-Japan Cooperative Program in Natural Resources panel on Wind and Seismic Effects. National Institute of Standards and Technology report NIST SP 796.

41. "Silicon Valley Rebounds Quickly After Quake Rattles Area Vendors." October 23, 1989. InfoWorld 11 (43).

42. Stepp, C. October 30, 1989. Facsimile to S.W. Swan.

43. Beck, D.L. November 1, 1989. "Area Wineries Shaken, but Survive the Quake." *San Jose Mercury News.*

44. Hardy, G. December 4, 1989. Facsimile to D.L. McCormick.

45. Roche, T. October 24, 1989. Facsimile to R. Kassawara.

46. Wilson, R.V. "The Earthquake of 1989. A Report on the San Francisco International Airport." Airports Commission.

47. "Companies in the Bay Area Assess Earthquake Damage." October 19, 1989. *The Wall Street Journal.*

48. Staehlin, W. January 23, 1990. "A Report to the Building Safety Board on the Performance of Hospital Buildings in the Loma Prieta Earthquake of October 17, 1989." Office of Statewide Health Planning and Development - Division of Facilities Development and Financing.

49. Swan, S.W. April 24, 1991. "CRTAPE1.DOC." Costa Rica Earthquake Reconnaissance Field Notes. San Francisco, CA. EQE Engineering, Inc.

50. Swan, S.W. April 28-30, 1991. "CRTAPE2.DOC." Costa Rica Earthquake Reconnaissance Field Notes. San Francisco, CA. EQE Engineering, Inc.

51. Swan, S.W. April 25, 1991. "CRTAPE3.DOC." Costa Rica Earthquake Reconnaissance Field Notes. San Francisco, CA. EQE Engineering, Inc.

52. Swan, S.W. April 26, 1991. "CRTAPE4.DOC." Costa Rica Earthquake Reconnaissance Field Notes. San Francisco, CA. EQE Engineering, Inc.

53. Swan, S.W. April 26-27, 1991. "CRTAPE5.DOC." Costa Rica Earthquake Reconnaissance Field Notes. San Francisco, CA. EQE Engineering, Inc.

54. Metal Building Manufacturers Association, Inc. (MBMA). "Loma Prieta (San Francisco) Earthquake of October 17, 1989 - Building Survey of the Epicenter Area."

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
actuator	Loma Prieta-1989	hvac	IBM Software Development, Santa Teresa	Air hoses from a few pneumatic valve actuators pulled loose within the HVAC system. In one case, this caused a valve on a chilled water line to fail closed cutting off the chiller's water supply.		1
airhandlers	Loma Prieta-1989	hvac	IBM Software Development, Santa Teresa	A cooling coil dislodged from its support framing within a rooftop air handler. A crack was found in another air handler's copper chilled water line.	The air handlers were equipped with isolation mounts that included lateral bumper restraints for seismic motion. Excessive bouncing on these mounts probably caused this minor cooling coil damage.	1
airhandlers	Loma Prieta-1989	hvac	Seton Medical Center, Daly City	An air handler unit broke free from its vibration isolators.		48
airhandlers	Loma Prieta-1989	hvac	Watsonville Community Hospital	Some of the ceiling-mounted air handlers broke free from their anchorage.		3
airhandlers	Whittier,CA-1987	hvac	Ticor Data Processing Center	The roof mounted HVAC air handlers shifted off their isolation mounts.	The isolators were not equipped with lateral restraining bumpers.	7-p4-19
batteries	Armenia,USSR-1988		Razdan Thermal Generating Station	Batteries fell from racks and were destroyed.	Batteries were unanchored.	34-p116
batteries	Armenia,USSR-1988		Spitak Substation	Batteries fell over and were damaged.	Batteries were unanchored.	34-p125
batteries	Armenia,USSR-1988		Thermo-generating Plant near Kirovakan	Batteries fell to floor and were destroyed.	Batteries were unanchored.	34-p116
boilers	Loma Prieta-1989		Hunter's Point Power Plant	A crack opened in the insulation cover atop one of the boilers for the larger steam unit.		1,4-p214
boilers	Loma Prieta-1989		Moss Landing Power Plant	Boiler units 6 and 7 had minor tube damage.		1,4-p321,24
boilers	Loma Prieta-1989		Watsonville Wastewater Treatment Plant	A few refractory bricks dislodged from the methane boiler's internal lining. The operators reported wastewater sloshing from the aeration basins and floating debris ejecting as far as five meters.		1
boilers	Loma Prieta-1989	structural	Moss Landing Power Plant	Buckled steelwork high in the boiler structure.	Impact of large diameter piping.	1,4-p321,24
boilers	Loma Prieta-1989	structural	Moss Landing Power Plant	Seismic restraint sheared off in the unit 7 boiler structure.	Pendulum rocking of the suspended boiler.	1,4-p208&321
boilers	Loma Prieta-1989	structural	Potrero Power Plant	Local yielding was noticed in the seismic restraints for one of the pendulum-supported boilers.		1,4-p214
boilers	Superstition Mt-1987		El Centro Steam Plant	The wide-flange seismic restraints on both sides (east and west) buckled.		14-p8
breakers	Armenia,USSR-1988		Electric Railroad Substation	110 kV circuit breakers toppled from short post support, damaging bushings and bus support.	Flexible short leg concrete support shifted.	34-p127
breakers	Armenia,USSR-1988		Kirovakan Substation	Damage similar to Leninakan-2, circuit breaker damage.		34-p125

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
breakers	Armenia,USSR-1988		Leninakan-2 Substation	Three 220-kV air-blast circuit breaker ceramic support columns failed.		34-p123
breakers	Armenia,USSR-1988		Razdan Thermal Generating Station	One of twenty-seven phases of air-blast circuit breakers failed.		34-p116
breakers	Armenia,USSR-1988	switches	Razdan Thermal Generating Station	Fourty-eight sets of three phase 220kV switches failed.		34-p116
breakers	Armenia,USSR-1988	transformers	Leninakan-2 Substation	Three 220-kV current transformers failed at connection between tall concrete support and metal base of the transformer.		34-p124
breakers	Costa Rica-1991	transformers	Institute of Costa Rican Electricity, railway substation near Limon	One of the 25 kV current transformers fell down and was severely damaged.	The transformer was not anchored.	53-p3
breakers	Gorman,CA-1988		Edmonston Pumping Plant, California Aqueduct	Ten of the sixteen 230 kV circuit breaker ceramic columns failed.	Both dynamic response and lack of slack in the conductors connecting adjacent equipment caused the failures.	11-p799,12
breakers	Gorman,CA-1988	interrupters	Edmonston Pumping Plant, California Aqueduct	Eighteen interrupter head gaskets blew.		11-p796,12
breakers	Loma Prieta-1989	arrestors	Metcalf Substation 500 KV Switchyard	A lightning arrester dislodged from its steel pedestal and fell to the ground adjacent to a transformer.		1,4-p327,25
breakers	Loma Prieta-1989	arrestors	Monte Vista Substation	A lightning arrester broke off one of the 230/115 KV transformers.		1,4-p335,29
breakers	Loma Prieta-1989	buses	Monte Vista Substation	Two overhead transfer buses serving the 230/115 KV transfer banks collapsed. One bar fell across the steelwork below, creating a short circuit in all 3 phases. The other bar hit the ground, fracturing a ceramic bell on a cable insulator string as it fell	The ceramic pedestals supporting the bus bars had little resistance to out-of-plane bending or torsional loads. On both buses one of the two bars dislodged from its supporting pedestal.	1,4-p335,29
breakers	Loma Prieta-1989	buses	Moss Landing 230 KV Switchyard	Failures occurred in several of the bus bar connections that bypass the structural steelwork between the power line and the disconnect switch.	The bypass bus bars lift off the power line near the tower, rising up to contact the disconnect switch atop its ceramic column. The bars have little out-of-plane resistance. The motion caused them short circuit with adjacent conductors.	1,4-p321,25
breakers	Loma Prieta-1989	buses	San Mateo Substation 115 & 60 KV Switchyards	There were instances of overturned rigid bypass bus connections that bridge over the steelwork between the flexible cable and the top of the disconnnect switches.		1,4-p334
breakers	Loma Prieta-1989	buses	San Mateo Substation 230 KV Switchyard	A bus bar dislodged on the overhead transfer bus serving one of the 230/115 KV transformer banks.	The bus bar disconnected from its ceramic posts and fell onto the steelwork below.	1,4-p334
breakers	Loma Prieta-1989	buses	San Mateo Substation 230 KV Switchyard	Several bypass bus bars rolled to one side until they made contact with the steelwork, creating a short circuit.		1,4-p334

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
breakers	Loma Prieta-1989	cables	San Mateo Substation 230 KV Switchyard	At two locations, the insulated ends of cables detached from their connections to the steelwork.	The insulated cable end hooks through a hole in the steel framing. The cables' whipping motion apparently allowed the hooks to detach.	1,4-p334
breakers	Loma Prieta-1989	ccvd	Monte Vista Substation	A capacitive coupling voltage device (CCVD) - also known as a voltage transformer potential device (VTPD) - broke off at the base of the ceramic column.		1,4-p335,29
breakers	Loma Prieta-1989	gaskets	Newark Substation	Gaskets on live-tank circuit breakers leaked.		4-p336,29-p8
breakers	Loma Prieta-1989	insulators	Moss Landing 550 kV Switchyard	The east transfer bus retained all three phases, but lost the support of one insulator post near the north end. The bar sagged at midspan between the remaining pedestal supports but did not collapse.		1,4-p208&321
breakers	Loma Prieta-1989	insulators	Moss Landing 550 kV Switchyard	The west transfer bus lost one of the three phases when the ceramic insulator posts broke off the top of the steel pedestals. The entire length of the bar fell to the ground.		1,4-p208&321
breakers	Loma Prieta-1989	interrupters	Metcalf Substation 500 KV Switchyard	Over 1/2 of the live tank circuit breakers were damaged. Of the 9 interupter head units, 3 had overturned columns. Most of the others just had broken porcelain. Several interrupter units shifted several inches from their anchor clamps.	Some temporary scaffolding installed for maintenance work overturned and damaged the columns of one circuit breaker assembly.	1,4-p327,25
breakers	Loma Prieta-1989	interrupters	Moss Landing 550 kV Switchyard	The 4 Westinghouse 500 kV SF6 gas live-tank circuit breakers were severely damaged; one of them overturned, all interrupter head support columns totally failed.	The reinforced support was inadequate because it was designed to a lower peak spectral acceleration than the circuit breaker probably experienced.	24-p74,28-p4
breakers	Loma Prieta-1989	interrupters	San Mateo Substation 230 kV Switchyard	All four GE live-tank circuit breaker assemblies suffered damage to a portion of their ceramic interrupter head support columns. Column damage ranged from broken gas seals at the base to shattered porcelain.	Rocking of the interrupter head ceramic support columns caused the seal gasket leakage.	1,4-p334,24
breakers	Loma Prieta-1989	linetraps	Moss Landing 550 kV Switchyard	The line trap and capacitive coupling voltage device (CCVD) are located on a single support assembly. One assembly had the line trap fail, three had the CCVD fail, and one had both fail.	Possible causes include inertial loads of the assembly and/or the long cable drop and also the lateral motion of the overhead bus.	29-p5
breakers	Loma Prieta-1989	switches	Metcalf Substation 500 KV Switchyard	Misalignments were found in a few of the disconnect switches where the blade failed to make proper contact with the receiving end of the switch.		1,4-p327,25
breakers	Loma Prieta-1989	switches	Metcalf Substation 500 KV Switchyard	One phase on a disconnect switch failed.	It was pulled down by the attached circuit breaker column.	1,4-p327,25
breakers	Loma Prieta-1989	switches	Monte Vista Substation	Several of the disconnect switches atop the steel support structure were misaligned. Two were inoperable.		1,4-p335,29

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
breakers	Loma Prieta-1989	switches	Moss Landing 230 KV Switchyard	Broken ceramic columns on disconnect switches and broken ceramic post insulators mounted atop the overhead steelwork.		1,4-p321,25
breakers	Loma Prieta-1989	switches	Moss Landing 550 kV Switchyard	25 of the 42 disconnect switches failed by failure of either or both lattice support columns.		29-p5
breakers	Loma Prieta-1989	switches	San Mateo Substation 230 KV Switchyard	Broken porcelain was reported on two disconnect switch columns mounted atop the steelwork.		1,4-p334
breakers	Loma Prieta-1989	switches	San Mateo Substation 230 KV Switchyard	Several disconnect switches were misaligned and had operational problems following the earthquake.		1,4-p334,29
breakers	Loma Prieta-1989	transformers	Metcalf Substation 500 KV Switchyard	Five current transformers leaked oil, however, the ceramic columns did not overturn or shatter. Prior to the earthquake, all rigid bus connections between the current transformers and the adjacent circuit breakers had been replaced with flexible cable.		1,4-p327,25
breakers	Loma Prieta-1989	transformers	Moss Landing 550 kV Switchyard	10 of the 12 current transformers failed by cracking of the porcelain member; one also had failed anchorage.	The support for the transformer is relatively flexible causing excessive vibration. Also, transformers connected to their circuit breakers rigidly failed whereas the 2 that were flexibly attached were not damaged.	29-p4
breakers	Newcastle,Aus-1989		Electricity Commission of New South Wales, Newcastle Substation, 132 kV Switchyard	Eight circuit breakers collapsed.		18,19-p6
breakers	Newcastle,Aus-1989		Electricity Commission of New South Wales, Newcastle Substation, 330 kV Switchyard	An oil-filled circuit breaker collapsed.	The insulator support base failed and caused the attached components to collapse.	18,19-p6
breakers	Newcastle,Aus-1989		Electricity Commission of New South Wales, Waratah Substation	Two circuit breakers collapsed.	The insulator support base failed and caused the attached components to collapse.	18,19-p6
breakers	Newcastle,Aus-1989	buses	Electricity Commission of New South Wales, Waratah Substation	A 132 kV bus collapsed.	The insulator support base failed and caused the attached components to collapse.	18,19-p6
breakers	Newcastle,Aus-1989	switches	Electricity Commission of New South Wales, Newcastle Substation, 132 kV Switchyard	Eight disconnect switches were damaged.	The collapsing attached circuit breakers pulled the attached components down.	18,19-p6
breakers	Newcastle,Aus-1989	transformers	Electricity Commission of New South Wales, Newcastle Substation, 132 kV Switchyard	Eight current transformers were damaged.	The collapsing attached circuit breakers pulled the attached components down.	18,19-p6

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
breakers	Newcastle,Aus-1989	transformers	Electricity Commission of New South Wales, Newcastle Substation, 330 kV Switchyard	A current transformer collapsed.	The insulator support base failed and caused the attached components to collapse.	18,19-p6
breakers	Newcastle,Aus-1989	transformers	Electricity Commission of New South Wales, Waratah Substation	Two current transformers collapsed.	The insulator support base failed and caused the attached components to collapse.	18,19-p6
breakers	Philippines-1990	arrestors	National Power Corporation, La Trinidad Substation near Baguio	The ceramic columns fractured near the base of several lightning arrestors.		17-p34
breakers	Philippines-1990	transformers	National Power Corporation, Cabanatuan Substation	Several current transformers were leaking oil at their rigid bus bar connections.	Interaction between adjacent current transformers via the rigid bus bars caused the leakage.	17-p33
breakers	Whittier,CA-1987		Southern California Edison, Center Substation	Six air tempered blast (ATB) circuit breakers leaked SF-6 insulating gas. One of the porcelain columns shattered.	Rocking of the ceramic columns atop the circuit breakers loosened the neoprene seal and allowed the SF-6 gas to leak.	7-p3-9,8-p31
breakers	Whittier,CA-1987		Southern California Edison, Del Amo Substation, Artesia	Most of the SF-6 gas-insulated air tempered blast (ATB) circuit breakers developed gas leaks in the ceramic column.	Rocking of the ceramic column causes leakage of SF-6 gas at the neoprene seal at the bottom of the column.	5p341,7p3-13
breakers	Whittier,CA-1987		Southern California Edison, Lighthype Substation	Two of the air tempered blast (ATB) circuit breakers had leakage of the SF-6 insulating gas.	Rocking of the ceramic columns atop the circuit breakers loosened the neoprene seal and allowed the gas to leak.	7-p3-16,8p31
breakers	Whittier,CA-1987		Southern California Edison, Mesa Substation	Eight air tempered blast (ATB) 220 Kv circuit breakers leaked SF-6 insulating gas.	Rocking of the ceramic columns atop the circuit breakers loosened the neoprene seal holding the insulating gas inside. The ceramic itself was not cracked.	7-p3-6,8-p31
breakers	Whittier,CA-1987	arrestors	Los Angeles Department of Water and Power, Substation B	Three 287 kV lightning arrestors damaged.		5-p340
breakers	Whittier,CA-1987	arrestors	Southern California Edison, Mesa Substation, Monterey Park	A lightning arrestor on a 220 kV transformer failed probably by exploding since fragments were so scattered.		5p341,7p3-6
breakers	Whittier,CA-1987	buses	Los Angeles Department of Water and Power, Renaldi Substation	Loss of SF-6 gas pressure in the gas-insulated bus tripped the circuit breaker deenergizing the bus.	Rocking of the ceramic tower atop the bus loosened the neoprene seal allowed the SF-6 gas to leak.	5-p340
cabinets	Armenia,USSR-1988	electrical	Spitak Sugar Refinery	Several electical panels overturned.	Poorly executed base welds failed.	34-p109
cabinets	Loma Prieta-1989		Electric Power Research Institute (EPRI) Headquarters, Palo Alto	Approximately 20% of the shelves and filing cabinets overturned. Even some library shelves that were braced together transversely and braced by rods longitudinally collapsed.	The connection of the diagonal to the shelves proved too weak for some of the heavier book inertial loads and the library shelves toppled from shear failure.	1

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
cabinets	Loma Prieta-1989		Rinconada Water Treatment Plant	Within the control building, bookshelves and filing cabinets overturned or emptied their contents.	These items were not (or inadequately) laterally braced.	1,4-p253
cabinets	Whittier,CA-1987		Pacific Bell local office	A heavy, wall-mounted cabinet attached with plastic expansion anchors to a plaster wall pulled away from the wall but did not fall. The cabinet did affect the surrounding equipment.		5-p355
cabinets	Whittier,CA-1987		Pacific Bell, Rosemead Switching Station	A floor mounted storage cabinet pulled out its anchor bolts attaching it to the wall behind and fell over, striking a switchrack but missing the rack-mounted instruments.		7-p4-10
cables	Armenia,USSR-1988		General Area	A set of 35-kV power lines was reported down.		34-p125
cables	Loma Prieta-1989		Pacific Bell Switching Station, Oakland	Some cables shifted off their wall-mounted brackets in the vault beneath the ground floor, but they were not damaged.		1
cables	Loma Prieta-1989		Rinconada Water Treatment Plant	Within the small computer room adjoining the control bay, two loose cable connections were found.	A central processing unit tilted into a raised-floor cable penetration and pulled one cable loose. The second one stretched as the cabinet shifted during the ground motion.	1,4-p253
cabletrays	Loma Prieta-1989		Pacific Bell Switching Station, Oakland	Heavily loaded cable trays failed at their supports in several locations, particularly in the 11th and 12th floor switching bays.	Support failures resulted from fracture of cast iron ceiling inserts and welds.	1,25-p19
cabletrays	Whittier,CA-1987		Pacific Bell local office	Cast-in-place rod hanger support inserts failed causing 5 or 6 rods to fall to the cable tray they supported.	Horizontal motion of the cable trays placed excessive bending loads on the inserts.	5-p355
cabletrays	Whittier,CA-1987		Pacific Bell local office	Support rods suspended from clips resting on channels that were part of the overhead cabletray bracing system fell off their channels.	Horizontal motion of the cable trays caused the clips to jump off their channels.	5-p355
cabletrays	Whittier,CA-1987		Pacific Bell, Alhambra Switching Station	Heavily loaded, rod hung cable trays failed by pulling out of their ceiling inserts and sagging. The cables themselves kept the trays from falling.	Swaying of the cable trays pried the clips apart attaching the trays to the rods. Also, the swaying pried some inserts out of the concrete ceiling.	7-p4-6
cabletrays	Whittier,CA-1987		Pacific Bell, Grand Central Switching Station, Los Angeles	The heavily loaded, rod hung cable trays came loose from their supports in several locations and sagged under their weight. The taut cables, however, kept them from falling.	Swaying of the cable trays pried the clips apart which attach the tray to the threaded rod.	7-p4-3
capacitors	Armenia,USSR-1988		Leninakan-2 Substation	Surge inductor base insulator broke pulling down one capacitor from bank.		34-p124
capacitors	Armenia,USSR-1988	transformers	Leninakan-2 Substation	Current transformers on two capacitor banks were damaged.		34-p124
ceilings	Alum Rock,CA-1988		East Ridge Mall, Tully Road east of Highway 101	Suspended ceilings fell in several department stores, typically concentrated around the perimeter.	Most suspended ceiling T-bar supports were not braced with cross wiring.	13
ceilings	Costa Rica-1991		Cachi Power Plant	A few ceiling panels fell to the floor.		52-p29

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
ceilings	Costa Rica-1991		Institute of Costa Rican Electricity, Moin Power Plant	Ceiling tiles fell in the mezzanine switchgear room.		21-p19
ceilings	Costa Rica-1991		Library about 39 Km South of Limon, Costa Rica	The suspended ceiling on the fourth floor of the library totally collapsed.	Generally poor construction as well as the excessive motion at the top of the library contributed to the ceiling collapse.	49-p9
ceilings	Loma Prieta-1989		Alta Bates Hospital, Berkeley	The acoustic ceiling tiles fell down as well as light fixture lenses.		48
ceilings	Loma Prieta-1989		Electric Power Research Institute (EPRI) Headquarters, Palo Alto	An estimated 5% of the acoustic ceiling panels dislodged and fell from their T-bar framing.		1
ceilings	Loma Prieta-1989		IBM Software Development, Santa Teresa	Fallen suspended ceiling fixtures created the major cleanup problem. A few heavier fixtures (i.e. lights and HVAC diffusers) dislodged.	The heavier fixtures were anchored to the concrete slab above by wire anchorages. About five of these failed. The ceiling T-bar framing apparently had no lateral bracing.	1
ceilings	Loma Prieta-1989		Laguna Honda Hospital, San Francisco	Acoustic ceiling tiles fell.		48
ceilings	Loma Prieta-1989		O'Conner Hospital, San Jose	Some of the acoustic ceiling tiles fell down.		48
ceilings	Loma Prieta-1989		Plantronics, Santa Cruz	The suspended T-bar ceilings buckled and moved enough to allow ceiling panels and lights fall throughout several areas of the building.	There was extensive movement between the separate units that made up the building.	54-p8
ceilings	Loma Prieta-1989		Rinconada Water Treatment Plant	A few suspended ceiling panels dislodged and fell in the control building offices.		1,4-p253
ceilings	Loma Prieta-1989		San Francisco International Airport	Many ceiling tiles had fallen down especially in the international and north terminals.		46
ceilings	Loma Prieta-1989		San Francisco International Airport Control Tower	Ceiling panels, light fixtures, and fiberglass acoustical insulation fell.	Inadequate or no lateral suspended ceiling bracing caused the damage.	4-p275,46
ceilings	Loma Prieta-1989		San Jose International Airport	Fiberglass soundproofing panels fell from the control room ceiling.		4-p279
ceilings	Loma Prieta-1989		San Jose Medical Center	Some of the acoustic ceiling tiles fell down.		48
ceilings	Loma Prieta-1989		Santa Clara Valley Medical Center, San Jose	Some of the acoustic ceiling tiles fell down.		48
ceilings	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	There were many instances where acoustic panels, lights, and ventilation diffusers fell from the T-bar framing.	The framing did not have adequate lateral bracing.	1,4-p202,41
ceilings	Loma Prieta-1989		Senate Sofa Beds, Soquel	There was minor buckling of the suspended T-bar ceiling.		54-p10

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
ceilings	Loma Prieta-1989		Stanford University Hospital	Some of the acoustic ceiling tiles fell down.		48
ceilings	Loma Prieta-1989		Stanford University library	The T-bar framing became very distorted and some ceiling panels fell.	There was no lateral bracing for the T-bar framing.	26-p114
ceilings	Loma Prieta-1989		The Furnace Room, Soquel	The suspended T-bar ceilings buckled in several locations in the front wooden portion of the building.		54-p9
ceilings	Loma Prieta-1989		Watsonville Community Hospital	The acoustic ceilings in the Administrative area were destroyed.		48
ceilings	Philippines-1990		Electronic Controller Manufacturing Corporation, Baguio Export Zone	Suspended ceilings and lights partially collapsed.		17-p31,20-p9
ceilings	Philippines-1990		Integrated Circuit Manufacturing and Testing Plant, Baguio Export Zone	Throughout the plant suspended ceilings collapsed causing damage to sensitive equipment below.	The T-bar supports for the ceiling panels were unbraced.	17-p28,20-p9
ceilings	Superstition Mt-1987		Central High School in Imperial	A few ceiling tiles fell around the perimeter of several rooms.		15-p4
ceilings	Superstition Mt-1987		Department Stores in Calexico	There was typical damage of perimeter ceiling tiles in suspended ceilings with T-bar framing.	There was insufficient bracing for the T-bars.	15-p5
ceilings	Whittier,CA-1987		14104-14112 Arbor Place, Cerritos	There was damage to suspended ceilings.		10-p18
ceilings	Whittier,CA-1987		6000 Slauson, Commerce CA	Ceiling tiles fell in the office area.	A steel angle of a truss (a chord) broke causing partial roof collapse.	10-p37
ceilings	Whittier,CA-1987		7633 Bequette Avenue, Pico Rivera CA	Extensive damage occurred to the suspended ceiling in both the office and manufacturing areas.		10-p3
ceilings	Whittier,CA-1987		9131 Perkins Street, Pico Rivera CA	Several lights suspended from the ceiling were damaged.		10-p4
ceilings	Whittier,CA-1987		Broadway Clearance Center, El Monte CA	Many ceiling tiles fell near the perimeter of the building at the first and second levels.		10-p23
ceilings	Whittier,CA-1987		California Federal Data Processing Center	Light fixtures throughout the building fell to the floor.		7-p4-22
ceilings	Whittier,CA-1987		California Federal Data Processing Center	Suspended ceiling panels and ducting dislodged and fell to the floor throughout the building.		7-p4-22
ceilings	Whittier,CA-1987		California State University Los Angeles - Salazar Hall	Most of the classrooms had severe ceiling damage with rather heavy hanging ceiling panels spread all over the rooms.		32-p3
ceilings	Whittier,CA-1987		City National Bank, Commerce CA	Ceiling tiles fell.		10-p39
ceilings	Whittier,CA-1987		City National Bank, Commerce CA	Light fixtures fell.		10-p39

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
ceilings	Whittier,CA-1987		City of Whittier, Water Office Building	The ceiling in the water office building fell during the earthquake.		22-p2
ceilings	Whittier,CA-1987		Lucky's Grocery Store, Whittier	Suspended ceiling panels dislodged and some fell to the floor.		32-p6
ceilings	Whittier,CA-1987		Nordstroms, Colorado Blvd and Central Ave, Glendale CA	Ceiling tiles fell and the T-bar framing supporting them became distorted.	Swaying sprinkler lines was partly to blame for the ceiling damage.	10-p13
ceilings	Whittier,CA-1987		Nordstroms, South Street and 1605, Cerritos CA	Ceiling tiles fell and the T-bar framing supporting them became distorted.		10-p14
ceilings	Whittier,CA-1987		Pacific Bell, Rosemead Switching Station	Several flourescent light fixtures which were clamped to cable tray supports dislodged and fell to the floor.		7-p4-9
ceilings	Whittier,CA-1987		Safeway Grocery Store, Hadley St., Whittier	Numerous suspended ceiling panels dislodged and fell to the floor.		8-p28,10-p8
ceilings	Whittier,CA-1987		Sanwa Data Processing Center	A large number of suspended ceiling panels dislodged and fell throughout the office and data processing areas.		7-p4-15
ceilings	Whittier,CA-1987		Shopping Center, Slauson Ave and Bequette Ave, Pico Rivera CA	Ceiling collapse occurred.		10-p27
ceilings	Whittier,CA-1987		Southern California Edison Headquarters, Rosemead	Flourescent light fixtures dislodged from supporting T-bar framing and fell into work areas.		7-p3-21,8p36
ceilings	Whittier,CA-1987		Southern California Edison Headquarters, Rosemead	Suspended ceiling panels dislodged from supporting T-bar framing and fell onto work areas.		7-p3-21,8p36
ceilings	Whittier,CA-1987		Ticor Data Processing Center	Large numbers of suspended ceiling light fixtures dislodged and fell.		7-p4-18
ceilings	Whittier,CA-1987		Ticor Data Processing Center	Large numbers of suspended ceiling panels dislodged and fell along with HVAC diffusers and intercom speakers.		7-p4-18
ceilings	Whittier,CA-1987		Wells Fargo Data Center	Both buildings had incidences of fallen suspended ceiling panels.		7-p4-13
ceilings	Whittier,CA-1987	equipment	California Federal Central Plant, Control Romm	Ceiling tiles fell onto the Beckman instumentation and control panel as well as the fact that the panel was sliding around, held upright only by conduit.	The panel was unanchored as well as the ceiling tiles.	6-pA29
ceilings	Whittier,CA-1987	hvac	City of Commerce Refuse-to-Energy Plant	A ventilation diffuser dislodged from the ceiling.		7-p3-32
chillers	Alum Rock,CA-1988		East Ridge Mall, Tully Road east of Highway 101	The vibration isolator supports for two chillers in one of the department store mechanical rooms were damaged.	Most of the isolation support mounts lacked any horizontal restraints. The equipment had no damage.	13

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Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
chillers	Loma Prieta-1989		Kaiser Foundation, Oakland	A large chiller anchor bolt loosened after the housekeeping pad cracked.		48
chillers	Loma Prieta-1989		O'Conner Hospital, San Jose	A chiller unit fell off of its vibration isolators.		48
chillers	Whittier,CA-1987		Broadway Department Store, Northridge Fashion Center	The chillers on the roof sustained damage to their isolation restraint supports.		10-p20
chillers	Whittier,CA-1987		California Federal Central Plant, Mechanical Room	Carrier chillers (all units) underwent east-west displacement as well as vertical as evidenced by the chipped concrete. Chiller #3 had failure but not leakage of flex connectors.		6-pA18
chillers	Whittier,CA-1987		Sanwa Data Processing Center	One HVAC chiller shifted off its isolation mount about 6 inches.		7-p4-16
chillers	Whittier,CA-1987	hvac	Ticor Data Processing Center	The roof mounted HVAC chillers shifted off their isolation mounts.	The isolators were not equipped with lateral restraining bumpers.	7-p4-19
clarifiers	Loma Prieta-1989	flocculators	Alvarado Wastewater Treatment Plant	Fiberglass baffles for four clarifiers were torn loose.	Wave action inside the basin caused the damage.	4-p262
clarifiers	Loma Prieta-1989	flocculators	Burlingame Wastewater Treatment Plant	The clarifier baffles were damaged.		23,40-p350
clarifiers	Loma Prieta-1989	flocculators	City of San Mateo Wastewater Treatment Plant	Fiberglass baffles for the secondary clarifier were damaged.	Wave action inside the basin caused the damage.	4-p262
clarifiers	Loma Prieta-1989	flocculators	Dublin/San Ramon Wastewater Treatment Plant	There was minor damage to two secondary clarifiers.		23,40-p350
clarifiers	Loma Prieta-1989	flocculators	Millbrae Wastewater Treatment Plant	Concrete clarifier covers sustained structural damage.	Differential Settlement of the clarifier caused the damage.	23,40-p350
clarifiers	Loma Prieta-1989	flocculators	Montevina Water Treatment Plant	The baffling on the static flocculator (coagulation) basin was destroyed.	Wave action inside the basin caused the damage.	4-p254,23
clarifiers	Loma Prieta-1989	flocculators	Palo Alto Wastewater Treatment Plant	Four out of six clarifiers were disabled when the fiberglass scum trough supports failed.	Wave action inside the basin caused the damage.	4-p261,23
clarifiers	Loma Prieta-1989	flocculators	Rinconada Water Treatment Plant	3 out of 4 clarifier basins suffered major damage to their steel radial launders and piping. Impellor motors, gear boxes, and sludge scapers were damaged. Mechanical couplings on the 30 inch in feed lines failed.	The launders sheared off their 5/8 inch anchor bolt connections at the basin walls. The central structure suffered torn welds and buckled steel plates from the sagging launders. This damaged the impellor motors and gear boxes and pulled the piping apart.	1,4-p253,23
clarifiers	Loma Prieta-1989	flocculators	Rinconada Water Treatment Plant	Steel framework was damaged within the clarification basins.	Waves of up to ~2 meters (~6 feet) were seen in the basins. These waves added drag and bouyant forces to the seismic inertial loads.	1,4-p253,23
clarifiers	Loma Prieta-1989	flocculators	San Leandro Wastewater Treatment Plant	The scum troughs on one of the clarifiers were damaged.		23,40-p350

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
clarifiers	Loma Prieta-1989	flocculators	South Bayside Wastewater Treatment Plant	Fiberglass baffles for clarifiers were torn loose.	Wave action inside the basin caused the damage.	4-p262
clarifiers	Loma Prieta-1989	flocculators	Sunnyvale Wastewater Treatment Plant	The sludge scraping system was disabled.	Wave action (sloshing) within the basin caused the damage.	23,40-p350
clarifiers	Loma Prieta-1989	flocculators	Tracy Water Treatment Plant	A sludge scraper jammed against the clarifier walls.		23,40-p350
clarifiers	Loma Prieta-1989	flocculators	Treasure Island Naval Wastewater Treatment Plant	There was settling of the clarifier and disablement of the sludge collection system.		23,40-p350
clarifiers	Loma Prieta-1989	flocculators	Union Sanitary District Wastewater Treatment Plant	There was minor damage to two primary sedimentation tanks and baffles.		23,40-p350
clarifiers	Loma Prieta-1989	flocculators	Watsonville Wastewater Treatment Plant	Existing cracks in fixed digester concrete cover opened up further.		23
compressors	Loma Prieta-1989	hvac	Electric Power Research Institute (EPRI) Headquarters, Palo Alto	HVAC items including refrigerant compressors, an air handler, and a water pump rolled off their spring isolation mounts but were undamaged.	Most spring mounts were not equipped with bumpers for limiting lateral displacements.	1
compressors	Whittier,CA-1987	hvac	Ticor Data Processing Center	The roof mounted HVAC compressors shifted off their isolation mounts.	The isolators were not equipped with lateral restraining bumpers.	7-p4-19
condensers	Loma Prieta-1989	structural	Potrero Power Plant	The steel struts bracing the water box inside the condenser suffered minor damage.		1,4-p214
condensers	Whittier,CA-1987		Southern California Edison, Lightype Substation, Long Beach	A rotating condensor showed different lubricating pressure across the bearings.	The bearings were misaligned.	5-p341
conduit	Alum Rock,CA-1988		East Ridge Mall, Tully Road east of Highway 101	A 1/2 inch conduit broke but the cables inside were not damaged.	The movement of a chiller unit caused the damage.	13
conduit	Loma Prieta-1989		Pillsbury Green Giant Storage Plant	Short circuits occurred in the conduit for the 480 KV power supply.	Several of the rod-hangers for the conduit trapeze failed although the conduit did not fall. Sidesway, however caused the conduit to puncture a junction box, which severed insulation on a nearby cable causing the short circuit. Corrosion was also evident	1,4-p191
ducts	Loma Prieta-1989	hvac	Electric Power Research Institute (EPRI) Headquarters, Palo Alto	Heavy HVAC diffusers dislodged from the ceiling framing and were left dangling from their flexible ducting.	Except for light fixtures no equipment was individually wired to the slab above. As a result, only one light fixture fell.	1
ducts	Loma Prieta-1989	hvac	O'Conner Hospital, San Jose	Some of the duct work pulled apart at the joints and some of the sway bracing pulled loose from its anchorages.		48

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
ducts	Loma Prieta-1989	hvac	Santa Teresa Community Hospital, San Jose	Some of the duct work broke their supports.		48
ducts	Whittier,CA-1987	hvac	California Federal Central Plant	HVAC ductwork collapsed with the suspended ceilings in the main building.		7-p4-24
elevators	Loma Prieta-1989		Children's Hospital, Oakland	Two elevators had cracked guide rail welds while one elevator had its counter weights pull out of their guide rails.		48
elevators	Loma Prieta-1989		Children's Hospital, San Francisco	Two of the seventeen elevators sustained guide rail and motor damage.		48
elevators	Loma Prieta-1989		Dominican Hospital, Santa Cruz	Two elevators had slightly damaged guide rails.		48
elevators	Loma Prieta-1989		Kaiser Foundation, Hayward	On one of the four elevators the rail clamps loosened.		48
elevators	Loma Prieta-1989		Kaiser Hospital, South San Francisco	One of the five elevators had its counter weights come out of their tracks.		48
elevators	Loma Prieta-1989		Mills Hospital, San Mateo	Four of the eight elevators had their counter weights come out of their rails.		48
elevators	Loma Prieta-1989		O'Conner Hospital, San Jose	One elevator sustained a bent frame, one had a roller wheel for the door fail, and another had a cracked motor case.		48
elevators	Loma Prieta-1989		Peninsula Hospital, Burlingame	Two elevators had their counter weights come out of their guides as well as had bent guide rails.		48
elevators	Loma Prieta-1989		San Francisco International Airport Control Tower	There was some damage to the control tower elevator.		4-p275
elevators	Loma Prieta-1989		San Jose Medical Center	One of the eight elevators sustained damage to its guide rails and counterweights.		48
elevators	Loma Prieta-1989		Santa Clara Valley Medical Center, San Jose	Elevator damage included bent or loosened guide rails and slipping counterweights.		48
elevators	Loma Prieta-1989		Santa Teresa Community Hospital, San Jose	One of the nine elevators sustained a bent rail anchor.		48
elevators	Loma Prieta-1989		Sequoia Hospital, Redwood City	One of the seven elevators had a twisted mounting bracket.		48
elevators	Loma Prieta-1989		Stanford University Hospital	One of the 41 elevators at this facility had a derailed counterweight.		48
elevators	Loma Prieta-1989		Watsonville Community Hospital	The hospitals four elevators suffered from bent guide rails and counter weights coming out of their guides.		48
elevators	Whittier,CA-1987		Throughout the Whittier area	10 instances of elevator guide rail anchor bolt pullout from hoistway walls.	These were attributed to older vintage of these buildings dating from the 30's.	5-p368

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
elevators	Whittier,CA-1987		Throughout the Whittier area	11 instances of elevator car damage.	The damage was caused by falling counterweights.	5-p369
elevators	Whittier,CA-1987		Throughout the Whittier area	91 instances of the derailment of elevator counterweights.		5-p368
equipment	Costa Rica-1991	electrical	Cachi Power Plant	An electrical governor on one of the diesel generators stopped functioning after the earthquake but had worked in recent tests. The problem at the time of the interview was unknown.		50-p11
equipment	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	Shifting of equipment was widespread within the production areas and machine shops. There were a few instances of overturned equipment.	In general, machinery was not anchored to the concrete floors in order to allow for easy rearrangement.	1,4-p202
equipment	Loma Prieta-1989	cabinets	IBM Software Development, Santa Teresa	There was noticeable equipment shifting within the computer bays. A few cabinets tipped over ar against adjacent equipment.	Computer cabinets are left unanchored to be easily relocated. Most of the tipped cabinets were not yet installed so they did not even have the restraining effect of cable connections through the raised floor.	1
equipment	Loma Prieta-1989	electrical	Lone Star Cement Plant, Davenport	An optical sensor located near the top of a vent stack was misaligned.		1
equipment	Loma Prieta-1989	electrical	Lone Star Cement Plant, Davenport	Some of the wiring in the electrostatic precipitators was damaged.	The large, suspended plates within the precipitators shifted and shorted some of the interconnecting wiring.	1
equipment	Loma Prieta-1989	electrical	Marley Roof Tile, Watsonville	The low voltage Abace Scandia relay system was burnt out during the earthquake.	According to the head electrician, the damage was caused by material the was tossed from the conveyor into the motor control center.	2
equipment	Loma Prieta-1989	electrical	San Francisco International Airport North Terminal	Several TV flight monitors fell from their supports above public seating areas.		4-p275,46
equipment	Loma Prieta-1989	electrical	San Francisco International Airport North Terminal	The United Airlines computer in the basement had water damage.	This was the result of the damaged sprinkling system releasing large amounts of water.	4-p275
equipment	Loma Prieta-1989	mechanical	National Refractories & Minerals in Moss Landing	Damage occurred in one of the three hydraulic presses for squeezing moisture from magnesia filter cake. These were located on the upper floor of the filter press building.	Sections of the compression framework dislodged from their guide rails.	1,4-p205
equipment	Loma Prieta-1989	mechanical	Soquel Water District	Level transmitters located on the sides of a few older tanks were damaged. Damage included broken ink lines and disconnected mechanical linkages in the pneumatic pressure sensors.	The damage could have been inflicted by the tank as it uplifted and slammed down on the concrete pad.	1
equipment	Loma Prieta-1989	mechanical	Watkins-Johnson Intrument Plant	Equipment shifted as much as 10 centimeters in the machine shops. There were no apparent misalignment problems.	No anchorage was present.	1,4-p199

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
equipment	Superstition Mt-1987	mechanical	El Centro Steam Plant	A rotary screw conveyor running between the tops of two concrete silos came out of alignment, but remained operational.	The conveyor could not accomodate the differential displacements at the top of the silos.	14-p10
equipment	Whittier,CA-1987		Pacific Bell local office	The cast aluminum feet securing the equipment to a one face of an equipment rack broke free from their fractured base anchors.	Overturning moments caused the anchor fracture.	5-p355
equipment	Whittier,CA-1987	electrical	California Federal Central Plant, Electrical Control Room	The southeast end of an ASCO generator control panel displaced northward about 6 inches but remained operable.		6-pA13
equipment	Whittier,CA-1987	electrical	Los Angeles Department of Water and Power, Substation B	Two 287 kV wave traps were damaged.		5-p340
equipment	Whittier,CA-1987	electrical	Pacific Bell, Rosemead Switching Station	A large number of circuit boards slid from their racks and hit the floor.	The only resistance to pullout is the small amount from their electrical plugs at the rear of the rack.	7-p4-9
equipment	Whittier,CA-1987	structural	Southern California Edison, Center Substation	A brace for one instrument panel pulled out from the wall.		7-p3-9
exchangers	Loma Prieta-1989		Moss Landing Power Plant & 550 kV Switchyard	The horizontal flow heat exchangers fell off their support rockers.	There were no seismic stops or anchors.	24-p72
exchangers	Loma Prieta-1989	structural	U.C. Santa Cruz Cogeneration	The anchor bolts attaching one end of the heat exchanger's shell to the supporting steel frame sheared.		1
fans	Alum Rock,CA-1988	hvac	East Ridge Mall, Tully Road east of Highway 101	The vibration isolator supports for two return fans in one of the department store mechanical rooms were damaged.	Most of the isolation support mounts lacked any horizontal restraints. The equipment had no damage.	13
fans	Loma Prieta-1989	hvac	Mills Hospital, San Mateo	Exhaust fans in the penthouse moved off of their mounting.		48
fans	Loma Prieta-1989	hvac	Mount Zion Hospital, San Francisco	Three fan units came off of their vibration isolators on the roof.		48
fans	Loma Prieta-1989	hvac	Peninsula Hospital, Burlingame	The exhaust fans in the penthouse moved off their vibration isolators.		48
fans	Loma Prieta-1989	hvac	Ralph K. Davies Hospital, San Francisco	A large roof-mounted fan unit came off of its supports.		48
fans	Loma Prieta-1989	hvac	Santa Teresa Community Hospital, San Jose	Some supply fans broke their vibration isolators.		48
fans	Loma Prieta-1989	hvac	Stanford University	Vibration isolators on a fan unit became permanently displaced.	There probably were no lateral stops on the isolation mount.	26-p117
fans	Loma Prieta-1989	hvac	Watkins-Johnson Intrument Plant	An axial flow fan, integral with a ceiling-supported HVAC duct, pulled loose its diagonal vibration restraints.		1,4-p199

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
fans	Loma Prieta-1989	towers	Watkins-Johnson Intrument Plant	Several roof fans and a small forced-draft tower dislodged from their spring mounts. The equipment was not damaged.	No lateral motion restaint existed.	1,4-p199
fans	Whittier,CA-1987	hvac	Sanwa Data Processing Center	Several axial fans shifted off their isolation mounts. In some cases, the expansion anchor bolts between the mounts and the concrete piers sheared.		7-p4-15
fans	Whittier,CA-1987	hvac	Southern California Edison Headquarters, Rosemead	Several HVAC fans dislodged from their isolation mounts in building GO-1. In one case the bellows coupling on the discharge side tore.		7-p3-21
fans	Whittier,CA-1987	hvac	Ticor Data Processing Center	The roof mounted HVAC fans shifted off their isolation mounts. Duct attachments also ruptured.	The isolators were not equipped with lateral restraining bumpers.	7-p4-19
flocculators	Costa Rica-1991		Water Treatment Plant near Rio Banano	There was some damage to the flocculators and also the sedimentation pond.		53-p10
generators	Costa Rica-1991		9 MW diesel powered plant in Changuinola, Panama	One of the seven serviceable diesel generators suffered a broken fuel line.	Differential settlement of the building relative to the generator caused the break.	21-p19
generators	Costa Rica-1991		Institute of Costa Rican Electricity, Moin Power Plant	A diesel generator had lost its shaft alignment.	Settlement caused the shaft rotation.	21-p19
generators	Loma Prieta-1989		Pacific Bell Switching Station, Oakland	Eight 1/2 inch anchor bolts on an out-of-service turbine generator pulled out. The generator was undamaged.	Building motion on the station's roof were very severe.	1
generators	Loma Prieta-1989		Pacific Bell Switching Station, Oakland	One of the roof-mounted, gas-turbine generators sheared its anchorage and shifted several centimeters, but remained operable.		1
generators	Loma Prieta-1989		Watsonville Community Hospital	A Cummings 450 kV generator jumped off its isolation springs. The load was transferred to a larger generator and the hospital kept operating.	There were no bumpers for limiting lateral movements.	3,33,40-p332
generators	Whittier,CA-1987		California Federal Central Plant, Mechanical/diesel room	Diesel generator #4, made by Waukesha, had its stack pull out of its engine at the manifold end.	There was no anchorage at this connection.	6-pA22
hvac	Alum Rock,CA-1988	bellows	East Ridge Mall, Tully Road east of Highway 101	There were several rips in flexible bellows connecting fans and air handling units to ducting.	Equipment movement damaged attachments such as bellows.	13
hvac	Loma Prieta-1989		San Jose International Airport	An air conditioning unit fell from the control room ceiling.		4-p279
hvac	Loma Prieta-1989	piping	Seagate Technology Disk Drive Plant,Scotts Valley	The HVAC unit on the roof shifted several centimeters. Attached conduit, water lines, and fuel lines were ruptured.	Differential displacements between the roof and the HVAC unit.	1,4-p202

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Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
incinerators	Loma Prieta-1989		City of San Mateo Wastewater Treatment Plant	The multiple hearth sludge incinerator was damaged.	The center shaft moved 2 to 4 feet in both directions damaging both the shaft and the refractory bricks.	4-p262
mcc	Alum Rock,CA-1988		East Ridge Mall, Tully Road east of Highway 101	The vibration isolator supports for a motor control center in one of the department store mechanical rooms were damaged.	Most of the isolation support mounts lacked any horizontal restraints. The equipment had no damage.	13
mcc	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	The anchor bolts attaching a motor control center to its wooden piers pulled out. The MCC serves the rooftop HVAC unit and did not overturn or shift off its piers.	Rocking of the MCC pulled the 3/8 inch coach bolt anchors completely out of the piers.	1,4-p202
motors	Loma Prieta-1989	compressors	Pillsbury Green Giant Storage Plant	Two 700 hp compressor motors had burned windings and required replacement.	The motors were triggered while the power supply was still fluctuating due to the earthquake prior to the local distribution grid's blackout. Power surges were likely caused by sway and circuits in transformers, switchgear, or conduit within the plant.	1,4-p191
motors	Loma Prieta-1989	elevators	Pacific Bell Switching Station, Oakland	The elevator's roof-mounted motors broke their anchorage and shifted several centimeters. The elevator slowly descended to the first floor , opened its doors, and shut down.	The failure was likely caused by loads imposed through the drive cables from the elevator which undoubtedly experienced substantial bouncing during the earthquake.	1
piping	Armenia,USSR-1988		Thermo-generating Plant near Kirovakan	There was a leak in a welded pipe.	Movement of the flexible 200mm header against rigid 60mm branch line.	34-p116
piping	Costa Rica-1991		RECOPE Refinery in Moin	There were several high-tempurature gas leaks within the refining installation which lead to a fire which was contained.		21-p29,52-p6
piping	Costa Rica-1991		RECOPE unloading port in Moin	Some piping fell down from its supports near the RECOPE refinery but did not get severely damaged.		51-p14&18
piping	Costa Rica-1991		Water Treatment Plant near Rio Banano	A 20 inch diameter steel water line sheared off. Also they have located from 50 to 60 other damaged areas of large bore piping.		53-p5&13
piping	Costa Rica-1991		Water Treatment Plant near Rio Banano	The piping to Moin has many leaks (termed waterspouts).		53-p12
piping	Gorman,CA-1988		Edmonston Pumping Plant, California Aqueduct	Two Smith-Blair mechanical couplings developed leaks in joints 4 and 9 of the older 192 inch diameter Pastoria siphon near the pump plant.	Either ground deformations or inertial loads were the cause but could not be definitively determined.	11-p796,12
piping	Loma Prieta-1989		Borland International, Scotts Valley	There was substantial damage to the marketing, product management, and research & Development departments caused by water from many broken pipes.		41-p1

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Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
piping	Loma Prieta-1989		Electric Power Research Institute (EPRI) Headquarters, Palo Alto	A crack developed in a 1/4 inch tube in one of the second floor mechanical rooms.	The tube was crushed against the ceiling by the supported chilled water line.	1
piping	Loma Prieta-1989		Electric Power Research Institute (EPRI) Headquarters, Palo Alto	A threaded coupling cracked at the junction of a 1 and 1/4 inch riser with a 4 inch main fire suppression header over a second floor corridor.	The failure was probably aggravated by impact from the adjacent section of sheet metal ducting.	1
piping	Loma Prieta-1989		Hunter's Point Power Plant	Denting of lagging and chipping of insulation around piping was noticed throughout the plant.		1,4-p214
piping	Loma Prieta-1989		IBM Software Development, Santa Teresa	A few leaks were discovered in the fire suppression lines mounted above the suspended ceilings.		1
piping	Loma Prieta-1989		IBM Software Development, Santa Teresa	Breaks occurred in two small PVC pipes routing chilled water beneath the raised floor in one computer bay.	Breaks occurred at the concrete wall penetrations so they are most likely due to differential displacements between the wall and the pipe supports attached to the raised floor.	1
piping	Loma Prieta-1989		IBM Software Development, Santa Teresa	Leaks were discovered in the 10 inch buried, cast-iron fire water headers which route water from tanks about 1 km from the plant. The tanks were undamaged.		1
piping	Loma Prieta-1989		IBM, San Jose	There was flooding due to broken water pipes.		47
piping	Loma Prieta-1989		Kaiser Foundation, Hayward	A 1-1/2 inch hot water supply line sheared off in the rooftop penthouse causing some flooding.		48
piping	Loma Prieta-1989		Kaiser Hospital, South San Francisco	Two hot water heating coils broke.		48
piping	Loma Prieta-1989		Laguna Honda Hospital, San Francisco	Some pipe supports fell causing the system to drop in some areas.		48
piping	Loma Prieta-1989		Lipton Food Dehydration and Packaging Plant	Two threaded couplings in the 1-1/2 inch fire lines developed minor cracks. The sprinkler head pipe hangers fell out of their ceiling anchorages.	Cracked couplings occurred where a short vertical span tried to resist the differential motion between two long, rod-hung, horizontal spans.	1,4-p196,45
piping	Loma Prieta-1989		Lone Star Cement Plant, Davenport	Leaks developed in a steel water line which was routed into the plant from the hills to the east.		1
piping	Loma Prieta-1989		Moss Landing Power Plant	Leaks in flanged couplings of gas pipes.	Soil subsidence caused support saddles to drop.	1,4-p208&321
piping	Loma Prieta-1989		Moss Landing Power Plant & 550 kV Switchyard	Piping insulation in some penetrations showed damage as well as seismic bumpers.	The main steam pipe for Unit 6 experienced 4 to 6 inch lateral displacements causing the damage.	28-p4

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
piping	Loma Prieta-1989		National Refractories & Minerals in Moss Landing	Leaks occurred in the welded steel line that supplies fresh water from a well about 1 kilometer inland from the site.	Liquifaction beneath the outdoor saddle supports caused sagging in the line which lead to leaking.	1,4-p205
piping	Loma Prieta-1989		National Refractories & Minerals in Moss Landing	One 4 inch, rod-hung, steel firewater line failed within the brick plant.	In the highbay structure, a long EW run of piping is interrupted by a short vertical riser which then branches into a NS run. The elbows at the top and bottom of the vertical portion broke trying to restrain the motion of the attached piping.	1,4-p205
piping	Loma Prieta-1989		National Refractories & Minerals in Moss Landing	The redwood line that carries seawater into the plant was found to have minor seepage from the seams following the earthquake.		1,4-p205
piping	Loma Prieta-1989		National Semiconductor Corp, Santa Clara	Piping in a wastewater treatment plant needed some immediate repairs.		47
piping	Loma Prieta-1989		Peninsula Hospital, Burlingame	Some piping for the chillers in the North Tower penthouse were broken.		48
piping	Loma Prieta-1989		Pillsbury Green Giant Storage Plant	Several ceiling-mounted cooling coils were damaged, and the attached refrigerant tubing leaked onto the produce below.	The coils were rod-hung and swayed violently during the earthquake. The refrigerant tubing cracked while resisting this motion. One hanger failed, but the others carried the extra load.	1,4-p191,33
piping	Loma Prieta-1989		Rinconada Water Treatment Plant	A crack developed in a small PVC pipe feeding chlorinated water into an underground vault housing a motor-operated valve. The valve operator had to be dismantled and repaired.		1,4-p253
piping	Loma Prieta-1989		San Francisco International Airport	A pipe support was broken.		4-p275
piping	Loma Prieta-1989		San Francisco International Airport North Terminal	Some fire suppression sprinkler heads sustained damage.	The damage was caused by interaction with the suspended ceiling.	4-p275,46
piping	Loma Prieta-1989		San Martin Winery	There was damage to the PVC piping running between the wine storage tanks.	Differential motion of the tanks caused overstresses in the pipes. Also, the piping did not have enough bends in it to make it flexible.	44
piping	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	A section of cast iron pipe about three meters long which was routed along the ceiling from a floor drain fell to the floor.	The pipe dislodged from its pipe hangers.	1,4-p202
piping	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	Fire sprinklers broke and sprayed much of the floor area.	Interaction with the suspended ceiling and wooden ceiling beams broke the sprinkler heads.	1,4-p202
piping	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	Threaded couplings in fire protection lines cracked at two locations in the main building.	Both cracks occurred in short interconnections between long horizontal runs of rod-hung pipe.	1,4-p202

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
piping	Loma Prieta-1989		Soquel Water District	Approximately 40 breaks occurred in the water system (most were 1 or 2 inch lines). One 8 inch cast iron water main and two 6 inch transit lines broke.		1
piping	Loma Prieta-1989		South of Market St., San Francisco	Six fire hydrants were damaged as well as a 12 inch diameter water main.	Soil deformations cuased the damage.	4-p245
piping	Loma Prieta-1989		St. Luke's Hospital, San Francisco	A heating hot water pipe and a steam pipe were broken in the mechanical penthouse.	There was relative motion between the fan/coil units and the next attachment for these two pipes.	48
piping	Loma Prieta-1989		U.C. Langley Porter Hospital, San Francisco	A hot water line to a reheat coil broke over a corridor.		48
piping	Loma Prieta-1989		U.C. Santa Cruz	Pipes broke at various locations around the campus.		1
piping	Loma Prieta-1989		United Motor Manufacturing Inc, Fremont	There were some water main ruptures in this facility.		47
piping	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	A 20 inch, buried water line ruptured.	There was an over-restrained elbow such that differential movement of the pipe caused a failure near the elbow.	4-p227
piping	Loma Prieta-1989		Watkins-Johnson Intrument Plant	Threaded couplings in fire protection line cracked at two locations - one in a rooftop penthouse, and the other in a second floor production.	Cracking in the penthouse piping may have been aggravated by the impact of adjacent pipes. In the production area, the crack seems to be caused by failure of the rod hangers. The subsequent sag caused overstress in the threaded coupling.	1,4-p199
piping	Loma Prieta-1989		Watsonville Community Hospital	A sprinkler line which crossed between two independent structures at the hospital without a flexible joint ruptured.	Differential displacements between the independent structures caused too much stress on the rigid pipe at that point.	33
piping	Loma Prieta-1989	tanks	Electric Power Research Institute (EPRI) Headquarters, Palo Alto	A crack developed in the soldered T-connection of a 1 inch copper line routed between a ceiling-mounted water tank and an HVAC boiler.	This failure appeared to be caused by differential displacement imposed between the top and bottom of the pipe by the rocking of the boiler.	1
piping	Loma Prieta-1989	tanks	French Hospital, San Francisco	A 1-1/4 inch pipe from a valve on a 500 gallon hot water storage tank to a heat exchanger was broken.		48
piping	Loma Prieta-1989	tanks	Hunter's Point Power Plant	A flange connection to a distilled water tank developed a small leak.		1,4-p214
piping	Loma Prieta-1989	tanks	Moss Landing Power Plant & 550 kV Switchyard	The flanged pipe connections on some distilled water tanks leaked. The tanks were housed within the base of the stacks for units 6 and 7.	The short pipe sections containing the flanges ran through the concrete stack walls and could not accommodate the stack rocking.	1,4-p208&321
piping	Loma Prieta-1989	tanks	Unspecified Tank Terminal/Refinery from Ref.4,p.219-(Richmond)	The bottom drain pipe of a 55 foot diameter, 20,000 barrel diesel fuel tank pried the bottom floor plate of the tank which tore a small hole.	Foundation uplift caused the failure.	4p232,25p24

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Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
piping	Newcastle,Aus-1989		Electricity Commission of New South Wales, Munmorah Substation	A demineralized water line was fractured.		19-p6
piping	Philippines-1990		Integrated Circuit Manufacturing and Testing Plant, Baguio Export Zone	Large diameter PVC piping supported by long rod hangers swayed enough to damage the piping as well as ducting.	The piping system was too flexible.	17-p28
piping	Saguenay,Quebec-1988		Chicoutimi church building, Quebec	A fuel oil line leading to a furnace broke and sprayed oil into the pilot light and ignited.		16-p6
piping	Saguenay,Quebec-1988		Chicoutimi industrial facility , Quebec	A propane leak from ruptured piping was sealed before it ignited.		16-p6
piping	Saguenay,Quebec-1988		Chicoutimi, Quebec	A gas line buried beneath the streets ruptured but was sealed before it ignited.		16-p6
piping	Superstition Mt-1987		Calexico Community Hospital	There was some piping leakage in the boiler room.		15-p4
piping	Superstition Mt-1987		El Centro Steam Plant	A 1 inch pipe leaked where a threaded joint connected to the Unit 3 deaerator tank.	This leak was probably caused by the inertia of the long unsupported length of pipe being connected.	14-p7
piping	Superstition Mt-1987		El Centro Steam Plant	An air line sheared at a threaded coupling.	Differential displacements between the processing building and a silo.	14-p10
piping	Superstition Mt-1987		El Centro Steam Plant	Insulation on a steam line in Unit 4 was dented when an adjacent pipe hit it.	The smaller pipe has too flexible laterally.	14-p9
piping	Superstition Mt-1987		Rockwood Peaking Plant	The pipe connection at the reverse osmosis tank outlet began to leak.		15-p7
piping	Whittier,CA-1987		Broadway Department Store, Cerritos Mall	A sprinkler pipe was severed and sprayed the area below.	The excessive motion of the clerestory above the pipe caused the break.	10-p21
piping	Whittier,CA-1987		California Federal Data Processing Center	The fire protection piping had pipe leakage and sprinkler head breaks throughout the building causing much water damage when the whole system was activated.	The pre-action fire protection system is activated by smoke detectors in the ceiling. It may have been activated by dust from falling debris or by malfunction.	7-p4-22
piping	Whittier,CA-1987		California State University Los Angeles - parking garage	A 10 inch diameter rod hung chiller pipe collapsed in the aftershock.	Poor hanger installation was thought to have been the cause.	10-p16,32-p3
piping	Whittier,CA-1987		City of Commerce Refuse-to-Energy Plant	A small water line attached to the potable water heater ruptured.	Apparently this was due to the rocking of the water heater.	7-p3-32
piping	Whittier,CA-1987		City of Glendale Power Plant	A 2 inch copper branch line ruptured at an elbow near its connection to a 20 inch circulating water line.	The 2 inch line is relatively stiff and acted as a brace for the unrestrained 20 inch line and caused rupture.	7-p3-28
piping	Whittier,CA-1987		City of Glendale Power Plant	The signal from a forced air flow monitor to a chart recorder became interupted.	The 1/4 inch signal line between the two devices became clogged, but plant operation was unaffected.	7-p3-28
piping	Whittier,CA-1987		Sanwa Data Processing Center	A 1/2 inch chilled water makeup line ruptured.	The attached HVAC chiller shifted about 6 inches and the 1/2 inch line did not have the flexibility to accomodate this motion.	7-p4-16

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Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
piping	Whittier,CA-1987		Sanwa Data Processing Center	A flexible run of fire protection piping near an expansion joint bounced excessively and broke off several sprinkler heads.	Piping run was too flexible.	7-p4-15
piping	Whittier,CA-1987		Sanwa Data Processing Center	Several of the rod hangers supporting 4 inch water lines failed by pulling out from the concrete ceiling.		7-p4-16
piping	Whittier,CA-1987		Southern California Edison Headquarters, Rosemead	Two small, ceiling-supported air handlers broke their attached 1 inch water lines.	This was due to the excessive swaying of the air handlers on their rod hangers.	7-p3-21
piping	Whittier,CA-1987		Ticor Data Processing Center	Fire portection piping ruptured in several locations within the building.	In most cases the ruptures were due to collapsing ceilings.	7-p4-19
piping	Whittier,CA-1987		Ticor Data Processing Center	Piping spanning across the expansion joint and braced on both sides of the joint experienced ruptures and broken braces.	There was excessive differential displacement between the two sides of the joint.	7-p4-20
piping	Whittier,CA-1987		Wells Fargo Data Center	A section of firewater piping in the parking structure sagged when its rod supports pulled out of the concrete ceiling.	The attachment here of the failed piping support to the ceiling was found to be "shot-in" concrete nails which were inadequate.	7-p4-12
piping	Whittier,CA-1987	chillers	Southern California Edison Headquarters, Rosemead	An HVAC chiller shifted several inches and ruptured a 4 inch condensate line.	The expansion anchors for the chiller had minimal thread engagement and pried loose as the chiller moved.	7-p3-21
pumps	Alum Rock,CA-1988		East Ridge Mall, Tully Road east of Highway 101	The vibration isolator supports for four horizontal pumps in one of the department store mechanical rooms were damaged.	Most of the isolation support mounts lacked any horizontal restraints. The equipment had no damage.	13
pumps	Philippines-1990		Baguio Water System	Eight of thirty-five submersible pump/motors were damaged following the earthquake.	Pump burn-out was attributed to voltage fluctuation from the power industry damage.	20-p5
pumps	Whittier,CA-1987		Sanwa Data Processing Center	A small horizontal pump serving the HVAC chiller suffered a broken impellor casing.	The dead weight and inertial loads from the failed 4 inch attached piping was now imposed on the pump instead of the rod hangers.	7-p4-16
pumps	Whittier,CA-1987	hvac	Ticor Data Processing Center	The roof mounted HVAC pumps shifted off their isolation mounts.	The isolators were not equipped with lateral restraining bumpers.	7-p4-19
structural	Costa Rica-1991		Fertilizer Plant near Port of Moin	Diagonal bracing and some ceiling panels (not suspended) broke and/or fell to the floor.		51-p19
structural	Loma Prieta-1989		Moss Landing Power Plant	Minor buckling in structural steel bracing.	Differential motion between boiler structures 6 and 7.	1,4-p321,24
structural	Loma Prieta-1989		San Francisco International Airport	There was significant shift in the runway-light support structure.	This could have been due to liquifaction.	4-p275
structural	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	Bolts at the bracing connections of the three-reactor service structure failed in combined shear and tension.		4-p221
structural	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	Buckling occurred in the gusset plates at Chevron bracing connections of a pipeway frame.	Eccentricity was not taken into account which probably contibuted to failure.	4-p226

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Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
structural	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	Leg supports and knee braces of the fan support structure buckled and braces were torn from their connections.	Undersized braces and insufficient moment capacity at the leg/brace connection coupled with a large supported mass contributed to the failure.	4-p221
structural	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	Some of the Chevron bracing in a three-reactor service structure buckled.	Excessive bracing slenderness coupled with eccentricity at the joints caused the failures.	4-p221
structural	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	Three inch bolts connecting a steel sidewalk to the columns pulled out.		4-p223
structural	Whittier,CA-1987		California Federal Data Processing Center	Two K-braces on the fourth floor at the ends of the building buckled. The wide flange braces bowed about 6 inches following the aftershock.		7-p4-22
structural	Whittier,CA-1987		Pacific Bell, Rosemead Switching Station	A diagonal ceiling brace restraining switchracks from transverse rocking pulled loose. The switchgear itself was unaffected.		7-p4-9
structural	Whittier,CA-1987		Shepard Decorating, 6858 Acco Street, Commerce CA	The wire bracing restraining a space heater snapped.		10-p1
switches	Whittier,CA-1987		Los Angeles Department of Water and Power, Substation B	Two ground switches were damaged.		5-p340
switchgear	Loma Prieta-1989		Continental Telephone, Gilroy	The electronics switch (AT&T 5 ESS) anchored to both floor and wall pulled its wall anchor bolts out.	Probably differential displacement between floor and wall caused the disconnection.	4-p297
switchgear	Loma Prieta-1989		Pacific Bell, San Jose	Two circuit packs (boards used in telephone equipment) came out of their sockets (mother board).		4-p297
switchgear	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	Switchgear that was part of an indoor substation supplying 480 Volt AC power to the production area required disassembly, drying, and reassembly.	The switchgear got sprayed with water when a sprinkler directly overhead was impacted by a ceiling beam.	1,4-p202
switchgear	Loma Prieta-1989	converters	Pacific Bell Switching Station, Oakland	Two DC voltage converters mounted in the third floor switchracks malfunctioned.	Apparently, the connection of electrical plugs supplying the converter at the rear lost adequate contact during the shaking. Even a momentary disturbance could have activated surge protectors on the converters. The units were'nt damaged,just destabilized	1
switchgear	Philippines-1990		Integrated Circuit Manufacturing and Testing Plant, Baguio Export Zone	Electrical switchgear overturned.		17-p28

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
switchgear	Whittier,CA-1987		California Federal Central Plant, Battery room	The Emperson DC Switchboard sheared its 1/2 inch shell type expansion anchor bolts. Panel remained undamaged and functional.		6-pA28
switchgear	Whittier,CA-1987		Pacific Bell, Rosemead Switching Station	A 600 pound switchrack supporting multiple relays sheared its anchorage of four 3/8 inch expansion anchors.		7-p4-10
tanks	Armenia,USSR-1988		General Spitak Area Tank Farms	Tanks sustained severe damage and some collapsed altogether.	Plate failures occurred to these tanks because they were unanchored and corroded thin wall mild steel. Collapse of short concrete support columns caused foundation failures.	34-p111
tanks	Costa Rica-1991		La Cruce de la Bomba	An elevated water tank collapsed.		53-p8
tanks	Costa Rica-1991		One of Several Tank Farms near the Port of Moin Refinery	Two 600 cubic meter welded-steel, oil-storage tanks suffered classic 'elephant foot' buckling at their bases.	Both tanks were full of oil and the sloshing of it during the shaking caused the buckling. The tanks were unanchored also.	21-p28,51p23
tanks	Costa Rica-1991		One of Several Tank Farms near the Port of Moin Refinery	Two tanks experienced severe buckling without loss of contents.		21-p28,52-p2
tanks	Costa Rica-1991		RECOPE Refinery in Moin	An oil-recycling tank exploded.	The tank overheated due to a fire which spread from inside the refinery and caused the tank to explode.	21-p29,52-p2
tanks	Costa Rica-1991		RECOPE Refinery in Moin	One 50,000 barrel, welded-steel, oil-storage tank ruptured and lost its contents.	The rupture apparently occurred at the base but it was covered in a lake of spilled oil at the time of inspection. The tank was full at the time of the earthquake.	21-p29
tanks	Costa Rica-1991		RECOPE Refinery in Moin	One of the oil storage tanks had its floating roof fall down as it was being repaired and killed one person.		52-p9
tanks	Costa Rica-1991	piping	One of Several Tank Farms near the Port of Moin Refinery	Piping was ruptured at one oil storage tank and the contents was lost.	The tank was unanchored and probably shifted, rupturing the attached piping.	21-p28
tanks	Loma Prieta-1989		Apple Cider Vinegar Plant, Watsonville	A 28 foot tall, 28 foot in diameter, 130,000 gallon vinegar storage tank suffered a severe elephant foot buckle (~ 1/3 of the circumference).	Sloshing of the vinegar in the damaged tank (which was full at the time) caused the buckle. The other three undamaged attached tanks were less than half full.	24-p108
tanks	Loma Prieta-1989		Bargetto Winery, Soquel	About 1,600 gallons of bulk wine spilled from a fermenting tank.		43-p9D
tanks	Loma Prieta-1989		Children's Hospital, Oakland	The deionization tanks pulled loose and spilled.		48
tanks	Loma Prieta-1989		Crescini Winery, Soquel	A stainless steel tank broke.		43-p9D
tanks	Loma Prieta-1989		French Hospital, San Francisco	Anchor bolts for two 500 gallon hot water storage tanks were broken.		48

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
tanks	Loma Prieta-1989		Los Gatos/San Jose Area	A 100,000 gallon, bolted-steel tank had an elephant foot buckle.	The tank was unanchored and therefore probably uplifted more than an anchored one would have.	4-p252,26
tanks	Loma Prieta-1989		Mirassou Winery, Aborn Road in San Jose	Three 15,000 gallon tanks were lost although most of the wine in them was salvaged.		43-p9D
tanks	Loma Prieta-1989		Moss Landing Power Plant & 550 kV Switchyard	Loss of contents of a 750,000 gallon raw water storage tank that was 75% full. The tank was 40 feet tall and 57.5 feet in diameter.	A seam at the unanchored, welded-steel tank's base opened. The depressurization buckled the wall near the roof. Corrosion was also a factor.	1,4,24,25
tanks	Loma Prieta-1989		Moss Landing Power Plant & 550 kV Switchyard	Several 2.4 meter diameter tanks suffered soil bearing failure and large settlements.	Liquifaction of the soil below the tank foundation induced large displacements.	26-p125
tanks	Loma Prieta-1989		Samuel Merritt Hospital, Oakland	Anchor bolts on the liquid oxygen tank were loosened allowing the tank to move about 3/4 of an inch.		48
tanks	Loma Prieta-1989		San Martin Winery	Many of the 20,000 gallon stainless steel outdoor storage tanks exhibited elephant foot or diamond buckling depending on how full the tank was.	Most of the tanks are 12 or 14 gauge steel. Some of the tanks that buckled in the 1984 Morgan Hill quake had been reinforced with thicker steel at the bottom wall course. In a few cases, the buckling shifted upward to a thinner course.	1,4-p192,24
tanks	Loma Prieta-1989		San Martin Winery	Many of the indoor tank anchorages pulled out and the concrete spalled around the embedded baseplates to which about 100 steel tanks were welded. The tanks each had an approxomate capacity of 20,000 gallons.	Rocking of the tanks and sloshing of the fluid inside caused the anchorages to pull out.	1,4-p192,24
tanks	Loma Prieta-1989		San Martin Winery	One of the twenty-four large oak casks (8,000 gallons) was damaged when it shifted off its supporting beams and fell against the adjacent brick wall.	The casks were unanchored and undoubtedly rocked substantially during the earthquake.	1,4-p192
tanks	Loma Prieta-1989		Silver Mountain Winery, Los Gatos	A 4,500 gallon water tank developed a leak on the bottom.		43-p9D
tanks	Loma Prieta-1989		Skaggs Island Naval Facility	An old elevated water tank had to be demolished due to the buckling of one of the steel frame legs.	The tank had a relatively high center of gravity.	26-p125
tanks	Loma Prieta-1989		Stanford University Hospital	One of the four legs of a liquid oxygen tank broke the weld between the leg and the baseplate.		48
tanks	Loma Prieta-1989		Unocal Refinery, Port of Richmond	Unocal terminal number 13 had a ruptured gasoline tank.		4-p286
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	A catwalk supported from the mid-height of a 48 foot tall, 30 foot diameter unanchored tank to a smaller tank at the other end punched a hole in the larger tank.	Both tanks responded differently and caused damage to the more flexible tank.	4-p234

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	The entire perimeter of a 500,000 gallon, 50 foot diameter gasoline tank had an elephant foot buckle. Also, the ladder came off its rail support.	Uplift occurred between the tank wall and the foundation pad.	4-p233
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	There was anchor bolt stretching of 1/2 of an inch in a 144 foot tall by 16 foot diameter vertical vessel.	Bolt yeilding provided necessary ductility for the vessel which was considered as part of the original design. This was not considered failure.	4-p228
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	There was anchor bolt stretching of 13/16 of an inch in a 171 foot tall by 22 foot diameter vertical vessel.	Bolt yeilding provided necessary ductility for the vessel which was considered as part of the original design. This was not considered failure.	4-p228
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219	There was damage to reinforced concrete piers supporting 25 foot long by 10 foot diameter horizontal vessels. Piers at one end had slotted base plates for thermal expansion.	Excessive shear in the anchor bolts caused the piers to crack. Base plates may have seized down due to corrosion, which would transfer higher loads into the piers than was expected.	4-p231
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219-(Richmond)	There was some distortion of two 20,000 gallon, 55 foot diameter tanks that interferred with the floating roof operation.	Ladders jumped off their supporting rails on top of the tanks.	4p232,25p24
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219-(Unocal)	The entire perimeter of a 300,000 gallon, 42.5 foot diameter lube oil tank had an elephant foot buckle. A rupture occurred at the junction of the buckle and the nozzle. The catwalk on top of the tank also fell.	Uplift from 6 to 8 inches occurred between the tank wall and the foundation pad.	4p233,25p25
tanks	Loma Prieta-1989		Unspecified Tank Terminal/Refinery from Ref.4,p.219-(Unocal)	There was a split in the wall of a 300,000 gallon, 42.5 foot diameter gasoline tank at the bottom plate. The ladder also came off its support rail.	Uplift from 6 to 8 inches occurred between the tank wall and the foundation pad.	4p233,25p25
tanks	Loma Prieta-1989		Vintners International Winery, Gonzales	Ten huge wine tanks ruptured.		43-p9D
tanks	Loma Prieta-1989		Watsonville	A 1,000,000 gallon, welded-steel tank buckled on one side near the roof. Also, the electronic water-level-transmitting device inside the tank was damaged.	Failure or yeilding of the roof rafter bracket caused the buckle while wave action inside the tank caused the transmitter damage.	4-p256,33
tanks	Loma Prieta-1989		Watsonville	The tank leg and base failed on an elevated, vertical oxygen tank about six feet in diameter and about 15 feet tall.		26-p120
tanks	Loma Prieta-1989		Watsonville Booster Pumping Facility	A 150 pound chlorine cylinder toppled over and released chlorine.	There was inadequate anchorage.	4-p256,33
tanks	Loma Prieta-1989	piping	J. Lohr Winery, San Jose	Two 16,000 gallon tanks ruptured and had to be replaced. Refrigerant lines broke also.		43-p9D

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
tanks	Loma Prieta-1989	piping	Pacific Bell Switching Station, Oakland	Piping broke on the roof and dumped water into the switching equipment on the lower floors.	A wooden cooling tower and a firewater plenum tank shifted off their foundations and broke the attached piping.	1
tanks	Loma Prieta-1989	piping	Soquel Water District	A few short piping connections near the base of tanks experienced leakage, but there was no substantial loss of contents before they were repaired.		1
tanks	Loma Prieta-1989	piping	Sunny Mesa	A 200,000 gallon, welded-steel tank was tilted off its foundation and an 8 inch inlet/outlet pipe was broken.		4-p256
tanks	Loma Prieta-1989	piping	Unspecified Tank Terminal/Refinery from Ref.4,p.219-(Unocal)	A foam pipe line at mid-height of a 300,000 gallon, 42.5 foot diameter gasoline tank pried a hole in the side of the tank. The pipe was restrained at the foundation. The ladder also came off its roof support.	Uplift from 6 to 8 inches occurred between the tank wall and the foundation pad.	4p233,25p25
tanks	Loma Prieta-1989	piping	Unspecified Tank Terminal/Refinery from Ref.4,p.219-(Unocal)	Restrained piping and conduit anchored between a 300,000 gallon, 42.5 foot diameter gasoline tank and its foundation was damaged. Also, the ladder came off its support rail.	Uplift from 6 to 8 inches occurred between the tank wall and the foundation pad.	4p233,25p25
tanks	Loma Prieta-1989	structural	San Martin Winery	The 20,000 gallon tanks are tied together at the top by a network of aluminum catwalks secured to the tanks by welds and diagonal bracing. A number of the welds and supports were broken.	Differential tank motion.	1,4-p192,44
tanks	Loma Prieta-1989	structural	Unspecified Tank Terminal/Refinery from Ref.4,p.219	There were fractured welds between embedded baseplates in the 104 foot tall by 11.5 foot diameter reactor vessels and their supporting braced frames.	Excessively large displacements occurred at the top of the reactor vessels as indicated by distressed connections of the catwalk at the tops of the vessels.	4-p231
tanks	Loma Prieta-1989	structural	Watsonville Community Hospital	A 3000 gallon, vertical liquid oxygen tank mounted on three legs jumped over and straddled its attached feed line network. Also one of the legs buckled.	The tank was anchored but the baseplate welds failed.	3,33,48
tanks	Manjil, Iran-1990		Lushan Cement Factory	Heavy feed containers shifted, load cell supports overturned, support bracing buckled.	Load cell supports were not capable of withstanding lateral loads.	36-p10
tanks	Manjil, Iran-1990		Rasht	Main water storage tank collapsed.	Operating elevated tank used unstable inverted pendulum configuration. Unused tanks had cracking at base.	35-p20,36,37
tanks	Philippines-1990		Caltex Tank Farm near the Port of San Fernando	Several tanks were tilted and there was observed differential settlement of 6 inches on a single tank bottom.		20-p8
tanks	Philippines-1990		Gas Stations in the Dagupan Area	Several gas stations had large, buried gas-storage tanks rise to the ground surface.	Liquifaction of the soil in which the tanks were buried caused them to float to the surface.	20-p8

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
tanks	Philippines-1990		Integrated Circuit Manufacturing and Testing Plant, Baguio Export Zone	Several unanchored tanks overturned.		17-p28
tanks	Philippines-1990		Tank farm near the Port of San Fernando	Many unanchored steel, oil-storage tanks settled from 8 to 12 inches. Two tanks appeared to be slightly buckled.	The buckling of the two tanks appears to be from differential settlement.	20-p8
tanks	Philippines-1990		University of the Philippines, Baguio campus	A 10,000 gallon steel-frame-supported vertical tank tipped over, bending the frame beyond repair.	The tank had a high center of gravity and the frame had minimal bracing.	17-p35
tanks	Superstition Mt-1987		El Centro Steam Plant	There was localized collapsing of the roof of a 45,000 barrel, fuel-oil storage tank. This tank (#4) is an unanchored, vertical tank 250 ft in diameter and 40 ft tall and it also shifted 1/8 inch to the southwest.	The tank shifted because it was unanchored.	14-p8,15-p6
tanks	Superstition Mt-1987		Rockwood Peaking Plant	Anchorage of a reverse osmosis water tank pulled out.		15-p7
tanks	Whittier,CA-1987		California Federal Central Plant, Mechanical/diesel room	The shell-type expansion anchor bolts of a diesel day tank partially pulled out.		6-pA25
tanks	Whittier,CA-1987		California Water Service Co, reservoir #5, East Los Angeles	The 8 inch anchor bolts stretched on a 500,000 gallon, riveted-steel tank 60 feet tall and 25 feet in diameter.		22-p15
tanks	Whittier,CA-1987		City of Alhambra, Department of Public works	A reinforced concrete storage tank cracked. The repair was done using epoxy.		22-p14
tanks	Whittier,CA-1987		City of Monterey Park	A 500,000 gallon, 30 feet tall by 70 feet diameter steel tank suffered anchor bolt distress.		5-p347
tanks	Whittier,CA-1987		City of Monterey Park	A small eleven foot tall steel tank had leakage from its joints.	The joints were weakened by corrosion.	5-p347
tanks	Whittier,CA-1987		City of Monterey Park, Reservoir #1, 470 Russell Avenue	Two 1,000,000 gallon, 1/2 buried concrete tanks suffered diagonal cracking on the tank floors.		5-p347,22-p7
tanks	Whittier,CA-1987		City of Monterey Park, Reservoir #7, 1400 Sombrero Drive	A 1,500,000 gallon, prestressed, wire-wrapped concrete tank about 30 feet tall had circumferential cracking about 1 1/2 feet below the water level and above the base.		5-p347,22-p7
tanks	Whittier,CA-1987		City of South Pasedena, La Portada	A 500,000 gallon, elevated welded-steel tank had some anchor bolts shear 1/4 inch at the base of the 8-leg support frame.		22-p22

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
tanks	Whittier,CA-1987		Rosemead, Burton Avenue	A 60 foot tall, 20 foot diameter Amarillo Water Company Tank experienced elongation equal to about 3/4 inch for each of the eight 2 inch diameter steel anchor bolts.		9-p59
tanks	Whittier,CA-1987	piping	City of Monterey Park	A 500,000 gallon steel tank had its drain pipe fractured.	Movement of the unanchored tank sheared off the drain pipe.	5-p347
tanks	Whittier,CA-1987	piping	Los Angeles Department of Water and Power, Mulholland	A 500,000 gallon, welded-steel tank developed a leak at the 4 inch drain.		22-p16
tanks	Whittier,CA-1987	piping	Park Water Co, 132nd Street and Salinas, Compton	A 500,000 gallon storage tank (tank 16A) which is 60 feet tall and 30 feet in diameter moved about one inch on its concrete footing. The inlet/outlet developed a small leak.		22-p18
tanks	Whittier,CA-1987	piping	San Gabriel Valley Water Co, 11727 Spyglass Hill Rd, North Whittier	A 611,000 gallon, unanchored, welded-steel tank separated from its coupling at the 10 inch inlet.	The tank moved since it was unanchored.	22-p20
tanks	Whittier,CA-1987	piping	San Gabriel Valley Water Co, 1401 Todd Pl, Montebello	A 611,000 gallon, unanchored, welded-steel tank developed a pencil-thin leak at the drain brace and a break at the 6 inch outlet to an abandoned pneumatic tank.	The tank moved since it was unanchored.	22-p20
tanks	Whittier,CA-1987	structural	California Water Service Co, reservoir #6, City Terrace	The tension bars stretched on the support structure of an elevated 600,000 gallon, welded-steel tank 70 feet tall.		22-p15
tanks	Whittier,CA-1987	structural	Rosemead, Grand Street near Walnut Grove	A number of diagonal tension-only steel bar braces buckled on the support structure for a Cal Am water tank.	The braces are long and very slender and susceptable to this kind of deformation. Also, the water tower has a very high center of gravity.	9-p58
towers	Alum Rock,CA-1988		East Ridge Mall, Tully Road east of Highway 101	The vibration isolator supports for a cooling tower in one of the department store mechanical rooms were damaged.	Most of the isolation support mounts lacked any horizontal restraints. The equipment had no damage.	13
towers	Armenia,USSR-1988	structural	Leninakan-Spitak Road	Apparent failure at top of base section splices lead to topling of the tower.		34-p133
towers	Loma Prieta-1989		Highland General Hospital, Oakland	A large cooling tower was racked over.		48
towers	Loma Prieta-1989		Monte Vista Substation	Steel truss towers supported the 230 KV buswork. The concrete pad supports for one of the towers had spalled.	The tower was anchored to the pads with expansion bolts rather than the standard cast-in-place anchorage. Working and partial pullout spalled the concrete on the pad's surface.	1,4-p335,29
towers	Loma Prieta-1989	structural	Lone Star Cement Plant, Davenport	Steel bracing on the third floor on the north side of the pre-heater tower stretched and buckled.		42

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
towers	Loma Prieta-1989	structural	Pillsbury Green Giant Storage Plant	Some steel members in the support framing of the evaporative cooling towers buckled.		1,4-p191
towers	Manjil, Iran-1990	structural	Sefidrud Dam	Tower collapsed.		36-p9
towers	Superstition Mt-1987	structural	El Centro Steam Plant	Bracing bolts on the east and west sides of a three story steel-frame tower sheared. Also, several expansion anchor bolts sheared at their connection to column bases.		14-p10
towers	Whittier,CA-1987	hvac	Ticor Data Processing Center	The roof mounted HVAC cooling tower shifted off their isolation mounts.	The isolators were not equipped with lateral restraining bumpers.	7-p4-19
transformers	Armenia,USSR-1988		Electric Railroad Substation	One 110 kV transformer overturned, two other toppled units damaged control cables and bus connections.	The transformers were unanchored.	34-p127
transformers	Armenia,USSR-1988		General Area	An unknown number of 35 kV, 10 kV, and 6 kV transformers fell off rails but remained operational since the rails are on grade.	The transformers were unanchored.	34-p125
transformers	Armenia,USSR-1988		Leninakan-1 Substation	Transformers fell from rail supports, some ceramic damage, and oil leakage.		34-p125
transformers	Armenia,USSR-1988		Razdan Hydro-generating Plant	A 330 kV three phase transformer failed at the base of the ceramic column.		34-p116
transformers	Armenia,USSR-1988		Razdan Thermal Generating Station	A small turbine field current transformer exploded one day after main event.		34-p116
transformers	Armenia,USSR-1988		Spitak Substation	110 kV transformers fell from rail supports, some bushing damage.		34-p125
transformers	Costa Rica-1991		Cachi Power Plant	Pole mounted transformers fell to the ground.		52-p23
transformers	Costa Rica-1991	piping	Institute of Costa Rican Electricity, low voltage substation near Limon	A rail-mounted transformer shifted off its foundation and broke the attached piping, spilling its oil contents.		21-p19
transformers	Gorman,CA-1988		Edmonston Pumping Plant, California Aqueduct	The radiator of a transformer in the adjacent switchyard developed a small leak.		12
transformers	Loma Prieta-1989		Booster Pumping Plant in the Santa Cruz Area	A wall-mounted transformer fell off its mounting but was not damaged.	There was inadequate anchorage.	4-p257
transformers	Loma Prieta-1989		Delphin Substation near Santa Cruz	The anchorage of three single-phase transformers failed allowing motion that caused arcing inside the transformers.		4-p336,29-p9
transformers	Loma Prieta-1989		Lone Star Cement Plant, Davenport	The plant's 69/4 kV transformer developed a minor oil leak.	The leak occurred where the bus duct penetrates the transformer tank. Probably differential displacements between the duct and the tank loosened the connection.	1
transformers	Loma Prieta-1989		Monte Vista Substation	One of the single-phase transformers in the 230/115 KV bank was found to be inoperable after the earthquake.	Apparently the earthquake damaged the transformer only internally.	1,4-p335

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
transformers	Loma Prieta-1989		San Francisco International Airport	A dry-type transformer that was part of a unit substation had a temporary short and caught fire ten days later.		4-p275
transformers	Loma Prieta-1989		San Francisco International Airport	A small, suspended transformer had shifted position.	The transformer support was not anchored.	4-p275
transformers	Loma Prieta-1989		San Jose International Airport	A small, dry-type transformer contacted its cabinet and arced but still remained functioning.		4-p279
transformers	Loma Prieta-1989		San Mateo Substation 115 & 60 KV Switchyards	Grouted-in-place anchor bolts pulled loose from the base slab of a bank of 115/60 KV transformers.		1,4-p334
transformers	Loma Prieta-1989		Seagate Technology Disk Drive Plant,Scotts Valley	A transformer that was part of an indoor substation supplying 480 Volt AC power to the production area required disassembly, drying, and reassembly.	The transformer got sprayed with water when a sprinkler directly overhead was impacted by a ceiling beam.	1,4-p202
transformers	Loma Prieta-1989		Throughout the affected area	Some pole-mounted distribution transformers slid over bolt heads on their mounting brackets and fell from their poles.	Possibly age deterioration accompanied with the seismic loads had a combined effect.	4-p336,29-p9
transformers	Loma Prieta-1989	piping	Metcalf Substation 500 KV Switchyard	Almost all of the single-phase transformers had oil leaks from flanged pipe connections to the radiator coils. One flange connection had buckled to the degree that the leak had to be stopped with epoxy.		1,4-p327,25
transformers	Loma Prieta-1989	piping	Metcalf Substation 500 KV Switchyard	Oil leaked from the broken seal on the bushing of a transformer unit.		1,4-p327,25
transformers	Loma Prieta-1989	piping	San Mateo Substation 230 KV Switchyard	Oil leaks developed at the flanged pipe connections supporting the radiators of four single-phase transformers. 700 gallons of oil spilled onto the ground.		1,4-p334,29
transformers	Manjil, Iran-1990		Sefidrud Dam	Several transformer stations were damaged.		36-p9
transformers	Philippines-1990		Baguio Water System	Five pole-mounted transformers failed when their poles collapsed. One ground-mounted transformer overturned.		20-p5
transformers	Whittier,CA-1987		California Federal Central Plant, Electrical Control Room	The core/coil of two General Electric dry-type transformers displaced and arced against its enclosure.	The core/coil assembly were not anchored inside the transformers.	6pA12,7p4-25
transformers	Whittier,CA-1987		Los Angeles Department of Water and Power, Renaldi Substation	A transformer cracked resulting in an oil leak.		5-p340
transformers	Whittier,CA-1987		Los Angeles Department of Water and Power, Substation P	A 220/345 kV transformer developed an oil leak and caught fire.	The internal winding had apparently shifted within the insulating oil bath, resulting in arcing that blew apart the ceramic casing.	5p340,7p3-26

Literature Search 1987-1991

Keyword 1	Earthquake	Keyword 2	Site	Description of Damage	Cause	Reference
transformers	Whittier,CA-1987		Sanwa Data Processing Center	A 75 kVA dry-type distribution transformer had loosened its anchor bolts for the core-coil framing and was making excessive noise. The bolts were tightened and the transformer remained operable.		7-p4-16
transformers	Whittier,CA-1987		Southern California Edison, Center Substation	A flexible cable dislodged from a lightning arrestor deenergizing one of the three-phase transformers.		7-p3-8
transformers	Whittier,CA-1987	piping	Southern California Edison, Olinda Substation	Several 220/66 kV transformers have slow leaks in the flanged piping to the radiator. Also several of these units showed signs of minor anchorage distress : weld tearing and concrete cracking.		7-p3-11
turbines	Loma Prieta-1989		Moss Landing Power Plant & 550 kV Switchyard	A turbine was found to have scored bearings supporting one end of the rotor.	Apparently, the oil film which supports the rotor was breached while the rotor spun at 1,800 RPM.	1,4-p208&321
turbines	Manjil, Iran-1990	generators	Loshan Power Plant	Misalignment of the of the Turbine-generator	2 inch settlement of the reinforced concrete pedestal.	35-p19
ups	Whittier,CA-1987		California Federal Central Plant	Anchor bolts pulled out about 1 1/2 inches on the Emerson uninteruptable power supply.		6pA30,7p4-24
ups	Whittier,CA-1987	inverters	Sanwa Data Processing Center	Several capacitors in the inverters of the uninterruptable power supply burned out.	There was a momentary power surge in the line serving the UPS.	7-p4-17
ups	Whittier,CA-1987	inverters	Sanwa Data Processing Center	Two inverters in the uninterruptable power supply sheared their expansion anchor bolts and slid several inches. The attached conduit was flexible enough for the inverters to remain operable.		7-p4-16
valves	Saguenay,Quebec-1988	piping	Alcan Facility, Arvida, Quebec	A safety valve was supposed to actuate with the loss of power but did not. This forced the uncontrolled release of 8 tons of toxic gas into the atmosphere.	It is unclear why the valve did not operate as expected since it tested fine just days before.	16-p8

Appendix C

Parameters for Fragility Function Used to Derive Basic Scores and PMFs

Table C-1

Index of Components Included in Screening Score Sheets
(Sorted Alphabetically by Component)

Component	Score Sheet	Classification
Air Handler	HV-02	HVAC Equipment
Alarm (fire pull station)	FP-01	Fire Protection Equipment
Alarm (smoke, fire, heat)	FP-01	Fire Protection Equipment
Battery Charger	EL-07	Electrical Equipment
Battery Rack	EL-06	Electrical Equipment
Boiler	MN-05	Mechanical Equipment
Cable	DS-03	Distribution Systems
Cable Entrance Facility	TC-01	Telecommunications Equipment
Cable Tray	DS-03	Distribution Systems
Chiller	HV-03	HVAC Equipment
Communications (microwave)	TC-02	Telecommunications Equipment
Communications (radio)	TC-02	Telecommunications Equipment
Communications (telephone)	TC-02	Telecommunications Equipment
Communications Control Equip.	MC-01	Miscellaneous Computer Equipment
Compressor	MN-03	Mechanical Equipment
Computer (mainframe)	MC-01	Miscellaneous Computer Equipment
Computer (micro, pc)	MC-01	Miscellaneous Computer Equipment
Computer (mini)	MC-01	Miscellaneous Computer Equipment
Computer (peripherals)	MC-01	Miscellaneous Computer Equipment
Conduit	DS-03	Distribution Systems
Control Panel	EL-04	Electrical Equipment
Cooling Tower	MN-04	Mechanical Equipment
Dampers (smoke, fire)	FP-02	Fire Protection Equipment
Detectors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Distribution Panel	EL-05	Electrical Equipment
Document Handling Equipment	MC-02	Miscellaneous Computer Equipment
Drum	TK-04	Tanks
Ductwork	DS-01	Distribution Systems
Electrical Power (off-site)	OS-01	Off-Site Systems
Elevator	MB-02	Miscellaneous Building Components
Elevator (derailment detector)	MB-02	Miscellaneous Building Components
Fan	HV-01	HVAC Equipment
Fire Extinguisher	FP-02	Fire Protection Equipment
Fire hose station	FP-02	Fire Protection Equipment

Table C-1 (Cont.)

Index of Components Included in Screening Score Sheets
(Sorted Alphabetically by Component)

Component	Score Sheet	Classification
Generator	EL-08	Electrical Equipment
Generator (portable)	ME-01	Miscellaneous Electrical Equipment
Heat Exchanger	TK-02	Tanks
Lighting (emergency stairway)	ME-02	Miscellaneous Electrical Equipment
Lighting (in suspended ceiling)	MB-01	Miscellaneous Building Components
Lighting (temporary)	ME-02	Miscellaneous Electrical Equipment
Media Rack	MC-02	Miscellaneous Computer Equipment
Medical Equipment (lab)	MD-01	Medical Equipment
Medical Equipment (unit)	MD-01	Medical Equipment
Monitors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Motor Control Center	EL-01	Electrical Equipment
Natural Gas (off-site)	OS-01	Off-Site Systems
Piping (above ground)	DS-02	Distribution Systems
Piping (buried)	DS-01	Distribution Systems
Piping (fire protection)	FP-03	Fire Protection Equipment
Power Transfer Equipment	ME-01	Miscellaneous Electrical Equipment
Pump	MN-01	Mechanical Equipment
Rack Mounted Components	TC-01	Telecommunications Equipment
Raised Access Floor	MB-01	Miscellaneous Building Components
Refrigerators (blood bank)	MD-01	Medical Equipment
Sensors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Sprinkler Head	FP-03	Fire Protection Equipment
Suspended Ceiling	MB-01	Miscellaneous Building Components
Switchgear	EL-02	Electrical Equipment
Tank (horizontal)	TK-02	Tanks
Tank (on legs)	TK-01	Tanks
Tank (vertical, anchored)	TK-03	Tanks
Tank (vertical, unanchored)	TK-05	Tanks
Transformer	EL-03	Electrical Equipment
Valve	MN-02	Mechanical Equipment
Valve (fuel shutoff)	FP-02	Fire Protection Equipment
Water, domestic (off-site)	OS-01	Off-Site Systems
Water, fire (off-site)	OS-01	Off-Site Systems

Table C-2

Index of Components Included in Rapid Visual Screening Score Sheets (sorted alphabetically by Score Sheet Identifier)

Component	Score Sheet	Classification
Ductwork	DS-01	Distribution Systems
Piping (buried)	DS-01	Distribution Systems
Piping (above ground)	DS-02	Distribution Systems
Cable	DS-03	Distribution Systems
Cable Tray	DS-03	Distribution Systems
Conduit	DS-03	Distribution Systems
Motor Control Center	EL-01	Electrical Equipment
Switchgear	EL-02	Electrical Equipment
Transformer	EL-03	Electrical Equipment
Control Panel	EL-04	Electrical Equipment
Distribution Panel	EL-05	Electrical Equipment
Battery Rack	EL-06	Electrical Equipment
Battery Charger	EL-07	Electrical Equipment
Generator	EL-08	Electrical Equipment
Alarm (fire pull station)	FP-01	Fire Protection Equipment
Alarm (smoke, fire, heat)	FP-01	Fire Protection Equipment
Detectors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Monitors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Sensors (smoke, fire, heat)	FP-01	Fire Protection Equipment
Dampers (smoke, fire)	FP-02	Fire Protection Equipment
Fire Extinguisher	FP-02	Fire Protection Equipment
Fire hose station	FP-02	Fire Protection Equipment
Valve (fuel shutoff)	FP-02	Fire Protection Equipment
Piping (fire protection)	FP-03	Fire Protection Equipment
Sprinkler Head	FP-03	Fire Protection Equipment
Fan	HV-01	HVAC Equipment
Air Handler	HV-02	HVAC Equipment
Chiller	HV-03	HVAC Equipment
Lighting (in suspended ceiling)	MB-01	Miscellaneous Building Components
Raised Access Floor	MB-01	Miscellaneous Building Components
Suspended Ceiling	MB-01	Miscellaneous Building Components
Elevator	MB-02	Miscellaneous Building Components
Elevator (derailment detector)	MB-02	Miscellaneous Building Components
Communications Control Equip.	MC-01	Miscellaneous Computer Equipment

Table C-2 (Cont.)

Index of Components Included in Rapid Visual Screening Score Sheets (sorted alphabetically by Score Sheet Identifier)

Component	Score Sheet	Classification
Computer (mainframe)	MC-01	Miscellaneous Computer Equipment
Computer (micro, pc)	MC-01	Miscellaneous Computer Equipment
Computer (mini)	MC-01	Miscellaneous Computer Equipment
Computer (peripherals)	MC-01	Miscellaneous Computer Equipment
Document Handling Equipment	MC-02	Miscellaneous Computer Equipment
Media Rack	MC-02	Miscellaneous Computer Equipment
Medical Equipment (lab)	MD-01	Medical Equipment
Medical Equipment (unit)	MD-01	Medical Equipment
Refrigerators (blood bank)	MD-01	Medical Equipment
Generator (portable)	ME-01	Miscellaneous Electrical Equipment
Power Transfer Equipment	ME-01	Miscellaneous Electrical Equipment
Lighting (emergency stairway)	ME-02	Miscellaneous Electrical Equipment
Lighting (temporary)	ME-02	Miscellaneous Electrical Equipment
Pump	MN-01	Mechanical Equipment
Valve	MN-02	Mechanical Equipment
Compressor	MN-03	Mechanical Equipment
Cooling Tower	MN-04	Mechanical Equipment
Boiler	MN-05	Mechanical Equipment
Electrical Power (off-site)	OS-01	Off-Site Systems
Natural Gas (off-site)	OS-01	Off-Site Systems
Water, domestic (off-site)	OS-01	Off-Site Systems
Water, fire (off-site)	OS-01	Off-Site Systems
Cable Entrance Facility	TC-01	Telecommunications Equipment
Rack Mounted Components	TC-01	Telecommunications Equipment
Communications (microwave)	TC-02	Telecommunications Equipment
Communications (radio)	TC-02	Telecommunications Equipment
Communications (telephone)	TC-02	Telecommunications Equipment
Tank (on legs)	TK-01	Tanks
Heat Exchanger	TK-02	Tanks
Tank (horizontal)	TK-02	Tanks
Tank (vertical, anchored)	TK-03	Tanks
Drum	TK-04	Tanks
Tank (vertical, unanchored)	TK-05	Tanks

Table C-3

Summary of Scores and Fragility Parameters

				Scores					Am	bc	HCLPF	
Conduit, Cable Trays, and Cable	DS-03	Distribution Systems										
			Basic Score	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**				
		1	Cable trays can slide off supports and fall.	3.2	3.8	4.1	4.7	5.0	1.9	0.5	0.60	
		2	Very heavily loaded cable trays.	2.8	3.4	3.7	4.3	4.6	2.5	0.5	0.80	
Ductwork	DS-03	Distribution Systems										
			Basic Score	5.3	4.8	4.4	3.9	3.5	1.9	0.5	0.60	
		1	Ducts can slide off supports and fall.	1.7	1.7	1.7	1.7	1.7	0.8	0.5	0.25	
		2	Inadequate flexibility where ducting crosses seismic gaps, between buildings, between equipment, etc.	2.0	2.0	2.0	2.0	2.0	0.6	0.5	0.20	
		3	Obvious heavy corrosion on duct	2.0	2.0	2.0	2.0	2.0	0.6	0.5	0.20	
		4	Duct supported by suspended ceiling	2.4	2.4	2.4	2.4	2.3	0.5	0.5	0.15	
Piping (above ground)	DS-01	Distribution Systems										
			Basic Score	5.7	5.2	4.8	4.3	3.9	2.5	0.5	0.80	
		1	No lateral support - possible falling of pipe.	1.9	1.9	1.9	1.9	1.9	0.9	0.5	0.30	
		2	Questionable vertical support system for pipe.	2.4	2.4	2.4	2.4	2.4	0.6	0.5	0.20	
		3	Short stiff branches attached to long flexible headers.	1.5	1.5	1.5	1.5	1.5	1.3	0.5	0.40	
		4	Inadequate flexibility where piping crosses seismic gaps..	1.9	1.9	1.9	1.9	1.9	0.9	0.5	0.30	
		5	Piping may impact rigid structural elements.	1.2	1.2	1.2	1.2	1.2	1.6	0.5	0.50	
Piping (buried)	DS-02	Distribution Systems										
			Basic Score	4.8	4.3	4	3.5	3.2				
			1a. Cast Iron Piping	1	1	1	1	1				
			1b. PVC Piping	1	1	1	1	1				
			1c. Reinforced Concrete or Asbestos Cement Piping	1.2	1.2	1.2	1.2	1.2				
			2. Poor Soil / Differential Settlement	1.2	1.3	1.3	1.4	1.4	0.8	0.5	0.25	
Motor Control Center	EL-01	Electrical Equipment										
			Basic Score	5.1	4.6	4.2	3.7	3.3	1.5	0.4	0.60	
			1. No anchorage	1.5	1.5	1.5	1.5	1.5	0.8	0.5	0.25	
			2. "Poor" anchorage	1.3	1.3	1.3	1.3	1.3	0.9	0.5	0.30	
			3. Suspect load path	0.7	0.7	0.7	0.7	0.7	1.4	0.5	0.45	
			4. Pounding or impact concerns	0.9	0.9	0.9	0.9	0.9	1.3	0.5	0.40	
			5. Interaction concerns	0.9	0.9	0.9	0.9	0.9	1.3	0.5	0.40	
Switchgear	EL-02	Electrical Equipment										
			Basic Score	4.8	4.3	3.9	3.4	3.0	1.3	0.4	0.50	
			1. No anchorage	1.0	1.0	1.0	1.0	1.0	0.9	0.5	0.30	
			2. "Poor" anchorage	0.8	0.8	0.8	0.8	0.8	1.1	0.5	0.35	
			3. Suspect load path	0.6	0.6	0.6	0.6	0.6	1.3	0.5	0.40	
			4. Pounding or impact concerns	0.5	0.5	0.5	0.5	0.5	1.4	0.5	0.45	
			5. Interaction concerns	0.6	0.6	0.6	0.6	0.6	1.3	0.5	0.40	
Transformer	EL-03	Electrical Equipment										
			Basic Score	5.2	4.7	4.3	3.8	3.4	1.6	0.4	0.65	
			1. No anchorage	1.7	1.7	1.7	1.7	1.7	0.8	0.5	0.25	
			2. "Poor" anchorage	1.4	1.4	1.4	1.4	1.4	0.9	0.5	0.30	
			3. Pounding/impact concerns	0.6	0.6	0.6	0.6	0.6	1.7	0.5	0.55	
			4. Poor load path	0.9	0.9	0.9	0.9	0.9	1.4	0.5	0.45	
			5. Interaction concerns	1.0	1.0	1.0	1.0	1.0	1.3	0.5	0.40	
			6. Coils not firmly restrained	1.2	1.2	1.2	1.2	1.2	1.1	0.5	0.35	
Control Panel	EL-04	Electrical Equipment										
			Basic Score	5.8	5.3	4.9	4.4	4.0	2.3	0.4	0.90	

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Summary of Scores and Fragility Parameters

				1. No anchorage	2.2	2.2	2.2	2.2	2.2	0.8	0.5	0.25
				2. "Poor" anchorage	2.0	2.0	2.0	2.0	2.0	0.9	0.5	0.30
				3. Suspect load path	2.2	2.2	2.2	2.2	2.2	0.8	0.5	0.25
				4. Pounding or impact concerns	1.2	1.2	1.2	1.2	1.2	1.7	0.5	0.55
				5. Inflexible attachments	2.2	2.2	2.2	2.2	2.2	0.8	0.5	0.25
				6. Interaction concerns	2.5	2.5	2.5	2.5	2.5	0.6	0.5	0.20
Distribution Panel	EL-05	Electrical Equipment										
				Basic Score	6.2	5.7	5.3	4.8	4.4	2.8	0.4	1.10
				1. No anchorage	2.4	2.4	2.4	2.4	2.4	0.9	0.5	0.30
				2. "Poor" anchorage	2.2	2.2	2.2	2.2	2.2	1.1	0.5	0.35
				3. Pounding or impact concerns	1.5	1.5	1.5	1.5	1.5	1.9	0.5	0.60
				4. Interaction concerns	1.5	1.5	1.5	1.5	1.5	1.9	0.5	0.60
Battery Rack	EL-06	Electrical Equipment										
				Basic Score	**6.0**	**5.5**	**5.1**	**4.6**	**4.2**	2.5	0.4	1.00
				1. No anchorage	2.2	2.2	2.2	2.2	2.2	0.9	0.5	0.30
				2. "Poor" anchorage	2.0	2.0	2.0	2.0	2.0	1.1	0.5	0.35
				3. No battery spacers	2.2	2.2	2.2	2.2	2.2	0.9	0.5	0.30
				4. No longitudinal cross-bracing	2.0	2.0	2.0	2.0	2.0	1.1	0.5	0.35
				5. No battery restraints	2.4	2.4	2.4	2.4	2.4	0.8	0.5	0.25
				6. Interaction concerns	2.4	2.4	2.4	2.4	2.4	0.8	0.5	0.25
Battery Charger	EL-07	Electrical Equipment										
				Basic Score	**5.6**	**5.1**	**4.7**	**4.2**	**3.8**	2.0	0.4	0.80
				1. No anchorage	1.8	1.8	1.8	1.8	1.8	0.9	0.5	0.30
				2. "Poor" anchorage	1.6	1.6	1.6	1.6	1.6	1.1	0.5	0.35
				3. Load path concerns	0.8	0.8	0.8	0.8	0.8	1.9	0.5	0.60
				4. Pounding or impact concerns	0.8	0.8	0.8	0.8	0.8	1.9	0.5	0.60
				5. Interaction concerns	1.4	1.4	1.4	1.4	1.4	1.3	0.5	0.40
Generator	EL-08	Electrical Equipment										
				Basic Score	5.6	5.1	4.7	4.2	3.8	2.0	0.4	0.80
				1. No anchorage	1.6	1.6	1.6	1.6	1.6	1.1	0.5	0.35
				2. "Poor" anchorage	1.4	1.4	1.4	1.4	1.4	1.3	0.5	0.40
				3. Vibration isolator concerns	1.4	1.4	1.4	1.4	1.4	1.3	0.5	0.40
				4. Rigid attachment concerns	2.0	2.0	2.0	2.0	2.0	0.8	0.5	0.25
				5. Driver/generator diff. displacement	2.0	2.0	2.0	2.0	2.0	0.8	0.5	0.25
				6. Interaction concerns	1.4	1.4	1.4	1.4	1.4	1.3	0.5	0.40
Alarm (fire pull station)	FP-01	Fire Protection Equipment										
				Basic Score	6	6	6	6	6			
			1	The pull stations are not marked, or access is blocked.	5	5	5	5	5			
Alarm (smoke, fire, heat)	FP-01	Fire Protection Equipment										
Detectors (smoke, fire, heat)	FP-01	Fire Protection Equipment										
Monitors (smoke, fire, heat)	FP-01	Fire Protection Equipment										
Sensors (smoke, fire, heat)	FP-01	Fire Protection Equipment										
				Basic Score	6	6	6	6	6			
			1	There is no regular inspection of the devices to insure proper function.	4	4	4	4	4			
			2	The devices are not properly mounted and could fall in an earthquake.	1.5	2.0	2.4	2.9	3.3	1.6	0.5	0.50
Dampers (smoke, fire)	FP-02	Fire Protection Equipment										
				Basic Score	6	6	6	6	6			
			1	There is no regular inspection of the devices to insure proper function.	3	3	3	3	3			
Fire Extinguisher	FP-02	Fire Protection Equipment										

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Summary of Scores and Fragility Parameters

Fire hose station	FP-02	Fire Protection Equipment										
			Basic Score	6	6	6	6	6				
			1 There is no regular inspection or maintenance of the units to assure reliable function.	4	4	4	4	4				
			2 Units are not accessible.	2.2	2.8	3.1	3.7	4.0				
Piping (fire protection)	FP-03	Fire Protection Equipment										
Sprinkler Head	FP-03	Fire Protection Equipment										
			Basic Score	5.0	4.4	4.1	3.5	3.2	1.6	0.5	0.50	
			1 No lateral support - possible falling of pipe.	0.8	0.8	0.8	0.8	0.8	1.3	0.5	0.40	
			2 Questionable vertical support system for pipe.	1.7	1.7	1.7	1.7	1.7	0.6	0.5	0.20	
			3 Short stiff branches attached to long flexible headers.	0.8	0.8	0.8	0.8	0.8	1.3	0.5	0.40	
			4 Inadequate flexibility where piping crosses seismic gaps..	0.9	0.9	0.9	0.9	0.9	1.1	0.5	0.35	
			5 Sprinkler heads could be damaged on impact.	2.1	2.1	2.1	2.0	2.0	0.5	0.5	0.15	
			6 Sprinkler heads are part of unbraced suspended ceiling.	2.4	2.4	2.3	2.3	2.3	0.4	0.5	0.12	
Valve (fuel shutoff)	FP-02	Fire Protection Equipment										
			Basic Score	7.2	6.6	6.3	5.7	5.4	4.0	0.4	1.60	
			1 There is no regular inspection of the valve to ensure proper function.	2	2	2	2	2				
			2 If manually controlled, unit is not accessible, or personnel are not trained in its use.	5	5	5	5	5				
Fan	HV-01	HVAC Equipment										
			Basic Score	5.0	4.4	4.1	3.5	3.2	1.6	0.5	0.50	
			1. No anchorage	1.4	1.4	1.4	1.4	1.4	0.8	0.5	0.25	
			2. "Poor" anchorage	1.1	1.1	1.1	1.1	1.1	0.9	0.5	0.30	
			3. Vibration isolator concerns	1.7	1.7	1.7	1.7	1.6	0.6	0.5	0.20	
			4. Fan/motor diff. displacement	0.9	0.9	0.9	0.9	0.9	1.1	0.5	0.35	
			5. Duct support concerns	0.8	0.8	0.8	0.8	0.8	1.3	0.5	0.40	
			6. Rigid attachment concerns	1.1	1.1	1.1	1.1	1.1	0.9	0.5	0.30	
			7. Interaction concerns	1.4	1.4	1.4	1.4	1.4	0.8	0.5	0.25	
Air Handler	HV-02	HVAC Equipment										
			Basic Score	5.2	4.7	4.3	3.8	3.4	1.9	0.5	0.60	
			1. No anchorage	1.7	1.7	1.7	1.7	1.7	0.8	0.5	0.25	
			2. "Poor" anchorage	1.4	1.4	1.4	1.4	1.4	0.9	0.5	0.30	
			3. Vibration isolator concerns	1.4	1.4	1.4	1.4	1.4	0.9	0.5	0.30	
			4. Duct support concerns	0.7	0.7	0.7	0.7	0.7	1.6	0.5	0.50	
			5. Rigid attachment concerns	2.0	2.0	2.0	2.0	1.9	0.6	0.5	0.20	
			6. Interaction concerns	1.2	1.2	1.2	1.2	1.2	1.1	0.5	0.35	
Chiller	HV-03	HVAC Equipment										
			Basic Score	5.4	4.8	4.5	3.9	3.6	2.1	0.5	0.65	
			1. No anchorage	1.2	1.2	1.2	1.2	1.2	1.3	0.5	0.40	
			2. "Poor" anchorage	0.9	0.9	0.9	0.9	0.9	1.6	0.5	0.50	
			3. Vibration isolator concerns	1.8	1.8	1.8	1.8	1.8	0.8	0.5	0.25	
			4. Piping support concerns	1.0	1.0	1.0	1.0	1.0	1.4	0.5	0.45	
			5. Interaction concerns	0.7	0.7	0.7	0.7	0.7	1.7	0.5	0.55	
Elevator	MB-02	Miscellaneous Building Components										

Summary of Scores and Fragility Parameters

Elevator (derailment detector)	MB-02	Miscellaneous Building Components										
			Basic Score	6	6	6	6	6				
		1	Cabs and counterweights are equipped with devices to detect detachment from rails.	5	5	5	5	5				
		2	Sheaves have guards to prevent slipping off of cables in an earthquake.	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40	
		3	Qualified personnel are not available to inspect elevators and allow restart in an earthquake.	5	5	5	5	5				
Lighting (in suspended ceiling)	MB-01	Miscellaneous Building Components										
Suspended Ceiling	MB-01	Miscellaneous Building Components										
			Basic Score	6	6	6	6	6				
		1	Where fallen ceiling tiles and frames could damage equipment, endanger workers or limit egress, there are no diagonal sway braces.	2.7	3.2	3.6	4.1	4.5	0.6	0.5	0.20	
		2	Light fixtures are not securely, independently anchored.	3.4	3.9	4.3	4.8	5.1	0.4	0.5	0.12	
Raised Access Floor	MB-01	Miscellaneous Building Components										
			Basic Score	6	6	6	6	6				
		1	There is no bracing, or other means, present to prevent excessive lateral motions.	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40	
Communications Control Equip.	MC-01	Miscellaneous Computer Equipment										
Computer (mainframe)	MC-01	Miscellaneous Computer Equipment										
			Basic Score	6	6	6	6	6				
		1	There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	2.4	3.0	3.3	3.9	4.2	0.8	0.5	0.25	
		2	There is a significant interaction hazard from something falling onto this equipment.	2.2	2.7	3.1	3.6	4.0	0.9	0.5	0.30	
Computer (micro, pc)	MC-01	Miscellaneous Computer Equipment										
Computer (mini)	MC-01	Miscellaneous Computer Equipment										
Computer (peripherals)	MC-01	Miscellaneous Computer Equipment										
			Basic Score	6	6	6	6	6				
		1	The units are not attached to tables or desks to prevent them from sliding and falling.	2.7	3.2	3.6	4.1	4.5	0.6	0.5	0.20	
		2	The tables or desks are unstable and likely to collapse.	1.2	1.8	2.1	2.7	3.0	1.9	0.5	0.60	
		3	The units are resting on the floor in such a way that overturning is likely.	2.2	2.7	3.1	3.6	4.0	0.9	0.5	0.30	

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Summary of Scores and Fragility Parameters

			4	There is a significant interaction hazard from something falling onto this equipment.	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40
Document Handler	MC-02	Miscellaneous Computer Equipment										
				Basic Score	6	6	6	6	6			
			1	There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40
Media Rack	MC-02	Miscellaneous Computer Equipment										
				Basic Score	6	6	6	6	6			
			1	There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40
			2	The media are not secured within the rack to prevent items from falling.	2.7	3.2	3.6	4.1	4.5	0.6	0.5	0.20
Medical Equipment (lab)	MD-01	Medical Equipment										
Medical Equipment (unit)	MD-01	Medical Equipment										
				Basic Score	6	6	6	6	6			
			1	Medical lab items are not secured to counters and tables.	2.2	2.7	3.1	3.6	4.0	0.9	0.5	0.30
			2	Medical lab items are stored on counters, tables, or carts that are likely to collapse.	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40
Refrigerators (blood bank)	MD-01	Medical Equipment										
				Basic Score	6	6	6	6	6			
			1	There is nothing to prevent overturning of the unit (unless it is of such size and weight that overturning is unlikely).	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40
Lighting (emergency stairway)	ME-02	Miscellaneous Electrical Equipment										
				Basic Score	6	6	6	6	6			
			1	There is no regular inspection or maintenance of the lighting units to assure reliable function.	1.5	2.0	2.4	2.9	3.3	1.6	0.5	0.50
			2	The units are not securely mounted to a wall or frame and could fall in an earthquake.	2.7	3.2	3.6	4.1	4.5	0.6	0.5	0.20
Lighting (temporary)	ME-02	Miscellaneous Electrical Equipment										
				Basic Score	6	6	6	6	6			
			1	There is no regular inspection or maintenance of the lighting units to assure reliable function.	1.5	2.0	2.4	2.9	3.3	1.6	0.5	0.50
			2	The lights are not stored in a readily accessible area known to the personnel who need them.	5	5	5	5	5			
Generator (portable)	ME-01	Miscellaneous Electrical Equipment										
				Basic Score	6	6	6	6	6			
			1	There is no regular inspection or maintenance to assure reliable function the generators.	1.5	2.0	2.4	2.9	3.3	1.6	0.5	0.50

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Summary of Scores and Fragility Parameters

		2	There are not personnel on hand who know how to operate the generators.	5	5	5	5	5				
		3	There is not a reliable fuel supply on hand for the generator.	5	5	5	5	5				
		4	The generator is stored in an area that will be difficult to access during an emergency situation.	5	5	5	5	5				
Power Transfer Equipment	ME-01	Miscellaneous Electrical Equipment										
			Basic Score	5.7	5.2	4.8	4.3	3.9	2.5	0.5	0.80	
		1	There are no restraints or anchorage to prevent the unit from overturning.	2.4	2.4	2.4	2.4	2.4	0.6	0.5	0.20	
Pump	MN-01	Mechanical Equipment										
			Basic Score	6.4	5.9	5.5	5.0	4.6	3.0	0.4	1.20	
			1. No anchorage	2.8	2.8	2.8	2.8	2.8	0.8	0.5	0.25	
			2. "Poor" anchorage	2.4	2.4	2.4	2.4	2.4	1.1	0.5	0.35	
			3. Vibration isolator concerns	3.1	3.1	3.1	3.1	3.1	0.6	0.5	0.20	
			4. Motor/pump displacement	1.9	1.9	1.9	1.9	1.9	1.6	0.5	0.50	
			5. Piping support concerns	2.2	2.2	2.2	2.2	2.2	1.3	0.5	0.40	
			6. Interaction concerns	1.7	1.7	1.7	1.7	1.7	1.9	0.5	0.60	
Valve	MN-02	Mechanical Equipment										
			Basic Score	7.2	6.6	6.3	5.7	5.4	4.0	0.4	1.60	
			1. Cast iron components and impact potential	2.9	2.9	2.9	2.9	2.9	1.3	0.5	0.42	
			2. Independent operator support	2.7	2.7	2.7	2.7	2.7	1.6	0.5	0.50	
			3. Rigid attachment concerns	3.5	3.5	3.5	3.5	3.5	0.8	0.5	0.26	
			4. Interaction concerns	2.3	2.3	2.3	2.3	2.3	2.1	0.5	0.65	
Compressor	MN-03	Mechanical Equipment										
			Basic Score	6.0	5.5	5.1	4.6	4.2	2.5	0.4	1.00	
			1. No anchorage	2.7	2.7	2.7	2.7	2.7	0.6	0.5	0.20	
			2. "Poor" anchorage	2.4	2.4	2.4	2.4	2.4	0.8	0.5	0.25	
			3. Vibration isolator concerns	1.8	1.8	1.8	1.8	1.8	1.3	0.5	0.40	
			4. Rigid attachment concerns	1.8	1.8	1.8	1.8	1.8	1.3	0.5	0.40	
			5. Interaction concerns	1.3	1.3	1.3	1.3	1.3	1.9	0.5	0.60	
Cooling Tower	MN-04	Mechanical Equipment										
			Basic Score	6	6	6	6	6				
		1	There are signs of deterioration on the structural members.	2.7	3.2	3.6	4.1	4.5	0.6	0.5	0.20	
		2	There is not a regular inspection program for this unit.	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40	
		3	Mounted on vibration isolators without lateral or uplift restraints.	2.7	3.2	3.6	4.1	4.5	0.6	0.5	0.20	
Boiler	MN-05	Mechanical Equipment										
			Basic Score	6	6	6	6	6				
		1	There is no anchorage or the anchorage is in poor condition (e.g., corrosion, cracking, etc.).	2.4	3.0	3.3	3.9	4.2	0.8	0.5	0.25	
		2	Attached items do not have adequate flexibility to accomodate potential seismic deflections.	2.2	2.7	3.1	3.6	4.0	0.9	0.5	0.30	

Table C-3 (Page 7 of 8)

Summary of Scores and Fragility Parameters

			3 Mounted on vibration isolators without lateral or uplift restraints.	2.4	3.0	3.3	3.9	4.2	0.8	0.5	0.25
Water , domestic (off-site)	OS-01	Off-Site Systems									
			Basic Score	3.7	3.2	2.8	2.3	1.9			
Electrical Power (off-site)	OS-01	Off-Site Systems									
			Basic Score	2.6	2.1	1.7	1.2	0.9			
Natural Gas (off-site)	OS-01	Off-Site Systems									
			Basic Score	5	5	5	5	5			
Water, fire (off-site)	OS-01	Off-Site Systems									
			Basic Score	3.7	3.2	2.8	2.3	1.9			
Cable Entrance Facility	TC-01	Telecommunications Equipment									
			Basic Score	6	6	6	6	6			
			1 The enclosure is in poor condition or has components that obviously require repair.	1.5	2.0	2.4	2.9	3.3	1.6	0.5	0.50
			2 The cables are in poor condition or obviously require repair.	1.6	2.2	2.5	3.1	3.4	1.4	0.5	0.45
			3 Not attached to the structure or on "poor" soil.	2.4	3.0	3.3	3.9	4.2	0.8	0.5	0.25
Communications (radio)	TC-02	Telecommunications Equipment									
Communications (telephone)	TC-02	Telecommunications Equipment									
			Basic Score	6	6	6	6	6			
			1 There is no regular inspection or maintenance of the systems to assure reliable function.	1.8	2.3	2.7	3.2	3.6	1.3	0.5	0.40
			2 Personnel on hand do not know how to operate the systems.	5	5	5	5	5			
Communications (microwave)	TC-02	Telecommunications Equipment									
			Basic Score	6.5	6.0	5.6	5.1	4.7	3.9	0.5	1.25
			1 The translation/control equipment is not restrained to prevent overturning.	2.9	2.9	2.9	2.9	2.9	0.8	0.5	0.25
			2 The tower and attached dish are not structurally adequately to prevent collapse.	2.0	2.0	2.0	2.0	2.0	1.6	0.5	0.50
Rack Mounted Components	TC-01	Telecommunications Equipment									
			Basic Score	4.8	4.3	3.9	3.4	3.0	1.3	0.4	0.50
			1 The rack is not braced or has no anchorage to prevent overturning.	1.0	1.0	1.0	1.0	1.0	0.9	0.5	0.30
			2 The components are not securely mounted to the rack.	1.3	1.3	1.3	1.3	1.2	0.8	0.5	0.25
Tank (on legs)	TK-01	Tanks									
			Basic Score	5.0	4.4	4.1	3.5	3.2	1.6	0.5	0.50
			1 Tank is unanchored or the anchorage is in poor condition.	1.4	1.4	1.4	1.4	1.4	0.8	0.5	0.25
			2 If anchored to a skid, the skid is unanchored.	0.8	0.8	0.8	0.8	0.8	1.3	0.5	0.40
			3 Attached piping is too rigid to withstand expected displacement.	1.1	1.1	1.1	1.1	1.1	0.9	0.5	0.30
			4 Legs appear to be undersized for weight of the tank or skirt has unreinforced opening.	1.1	1.1	1.1	1.1	1.1	0.9	0.5	0.30
Tank (horizontal)	TK-02	Tanks									
Heat Exchanger	TK-02	Tanks									
			Basic Score	6.0	5.5	5.1	4.6	4.2	3.0	0.5	0.95

Summary of Scores and Fragility Parameters

			1	Vessel is unanchored or the anchorage is in poor condition.	1.8	1.8	1.8	1.8	1.8	1.3	0.5	0.40	
			2	Tank is not attached to saddle.	2.2	2.2	2.2	2.2	2.2	0.9	0.5	0.30	
			3	Attached piping is too rigid to withstand expected displacement.	2.0	2.0	2.0	2.0	2.0	1.1	0.5	0.35	
			4	Shells of stacked heat exchangers are not secured together.	2.4	2.4	2.4	2.4	2.4	0.8	0.5	0.25	
Tank (vertical, anchored)	TK-03	Tanks											
				Basic Score	5.2	4.7	4.3	3.8	3.4	1.9	0.5	0.60	
			1	The anchorage is in poor condition.	1.7	1.7	1.7	1.7	1.7	0.8	0.5	0.25	
			2	Anchor details are non-ductile or could tear the shell.	1.4	1.4	1.4	1.4	1.4	0.9	0.5	0.30	
			3	Attached piping is too rigid to withstand expected displacement.	1.0	1.0	1.0	1.0	1.0	1.3	0.5	0.40	
			4	Tank is made of stainless steel.	1.7	1.7	1.7	1.7	1.7	0.8	0.5	0.25	
			5	Tank is made of fiberglass or similar material.	2.0	2.0	2.0	2.0	1.9	0.6	0.5	0.20	
Drum	TK-04	Tanks											
				Basic Score	6.5	6.0	5.6	5.0	4.7	3.8	0.5	1.20	
			1	The units are not restrained with straps to keep them from overturning.	2.5	2.5	2.5	2.5	2.5	1.1	0.5	0.35	
			2	The drums are stacked very high on pallets.	2.7	2.7	2.7	2.7	2.7	0.9	0.5	0.30	
Tank (vertical, unanchored)	TK-05	Tanks											
				Basic Score	6.5	5.5	4.5	3.5	2	2.0			
				1. Riveted shell seams	2.1	2	1.3	0.5	0	0.0			
				2. Rigid pipe attachments	3.6	2.6	1.6	2	2	2.0			
				3. Shell thickness unknown	1	1	1	1	2	2.0			
				Note that TK-05 has six load levels, dependent on location and aspect ratio.									

Part C

Model Code Provisions

1. General
2. Identification of Critical Systems and Components
3. Component Evaluation
4. Systems Evaluation
5. Risk Management

PREFACE

MODEL CODE PROVISIONS

This section of the report contains an example of model code provisions incorporating the information provided in Parts A and B to this document. The model code provisions are written and formatted as a stand alone document to demonstrate one possible means of compiling and presenting these data such that they can be used by code makers and regulatory officials.

The example method chosen is referred to as a "Recommended Practice" throughout the remainder of Part C. This particular term is used in the petrochemical industry for many documents prepared by the American Petroleum Institute (API) for use in designing petrochemical facilities for a variety of hazards. Many Recommended Practices have been adopted as design codes by governing authorities.

We have used this particular term rather than other possible terms such as "Code" or "Standard" because we feel it is a better representation of the intent and philosophy of the document. We also have structured the framework for this Recommended Practice in a similar way as done in API Recommended Practices applicable to hazards analyses for offshore platforms and onshore facilities. This is appropriate because many similarities exist in the techniques and skills utilized in those analyses as in the systems analyses used in the approach presented in this document.

The Recommended Practice presented herein is also formatted differently from the remainder of the document. This was necessary to present the model code provisions as a stand alone example document.

PART C: MODEL CODE PROVISIONS
DETAILED TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1
GENERAL

1.1 INTRODUCTION

For many years model code provisions have addressed the design of equipment systems for seismic loads in a limited manner, typically addressing only the structural design of anchorage or attachments. This recommended practice presents a systematic method for evaluating the equipment systems of existing facilities for seismic loads, considering the proven effects of earthquakes on the ability of a facility to continue providing critical services. Proper application of this practice, along with proper maintenance and emergency preparedness should decrease the economic impact of earthquake damage to important facilities.

1.2 SCOPE

This document presents recommendations for evaluating the reliability of important facilities and their ability to continue providing critical services after an earthquake. The basic concepts of the evaluation methodology are discussed and mitigation methods are presented.

a) This recommended practice describes how critical systems and critical components can be identified for a facility. A method is provided for systematically reviewing important systems and the impact of their failure on other important systems. A means is provided to incorporate special considerations, such as emergency plans, personnel actions, and known maintenance problems.

b) This recommended practice provides a method for rapidly, but systematically evaluating the reliability of critical systems in an earthquake. A scoring system is provided to quantify the relative reliability of systems and components.

c) In addition, a method is provided for rapidly evaluating individual equipment components and incorporating those evaluations into the system evaluation. That method uses assessment techniques based on historical earthquake performance of similar equipment items. Assessments are made of specific items that have been known to be causes of damage in past earthquakes, or known to be seismically vulnerable for other reasons.

d) This recommended practice also provides suggestions for risk mitigation and more detailed assessment. The assessment methodology presented in this guidance is intended as a screening technique. It should be used in conjunction with more detailed analyses and review of emergency plans in making upgrade decisions.

e) This recommended practice does not address reliability of the structural adequacy of building structures. All assessments are predicated on the assumption that other means will be used to evaluate and strengthen buildings, as necessary, such that damage to the building itself will not affect the reliability of critical equipment systems.

1.3 ORGANIZATION OF TECHNICAL CONTENT

The technical content of this recommended practice is arranged as follows:

Section 2 - A recommended method for identification of critical systems and critical components, and the interdependencies between different components and systems.

Section 3 - A discussion of the methods of evaluating individual components and the technical basis.

Section 4 - The recommended method for quantification of system reliability, including concepts and methodology.

Section 5 - A detailed discussion of risk management, including mitigation techniques and methods for performing more refined analytical investigations.

1.4 POLICY

This recommended practice has been prepared as a result of research sponsored by the Multidisciplinary Center for Earthquake Engineering Research (MCEER). MCEER was established to expand and disseminate knowledge about earthquakes, improve earthquake-resistant design, and implement seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures in the eastern and central United States and lifelines throughout the country that are found in zones of low, moderate, and high seismicity. To that end, this recommended practice was prepared to facilitate the availability and implementation of sound engineering and operating practices that will increase the likelihood of availability of important services following an earthquake.

Nothing in this recommended practice is intended to preclude the need to apply sound judgment as to when and where this recommended practice should be utilized. The formulation and publication of this recommended practice is not intended to, in any way, inhibit anyone from using any other practice. Nothing contained in this recommended practice is to be construed as granting any right, by use in connection with any method, apparatus, or product covered by letters patent, nor as insuring anyone against liability for infringement of letters patent. This recommended practice may be used by anyone desiring to do so, and a diligent effort has been made by the authors to assure the accuracy and reliability of the data contained herein. However, neither MCEER nor any other concerned party makes any representation, warranty or guarantee in connection with the publication of this recommended practice and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use, for any violation of any federal, state, or municipal regulation from which a recommendation may conflict, or for the infringement of any patent resulting from use of this document.

1.5 GOVERNMENT CODES, RULES, AND REGULATIONS

Regulatory agencies have established certain requirements for the design, installation, and operation of facilities in their jurisdiction. In addition to federal regulations, certain state and local regulations may be applicable. The following federal documents may pertain to facilities to which this recommended practice may be applicable and should be used when appropriate. Other documents not listed may also be applicable to certain types of facilities.

a) Executive Order 12941, "Seismic Safety of Existing Federally Owned or Leased Buildings," signed by President Clinton, December 1, 1994.

b) ICSSC RP 4, NISTIR 5382, "Standards of Seismic Safety for Existing Federally Owned or Leased Buildings and Commentary," National Institute of Standards and Technology, February 1994.

c) ICSSC RP 5, NISTIR 5734, "ICSSC Guidance on Implementing Executive Order 12941 on Seismic Safety of Existing Federally Owned or Leased Buildings," National Institute of Standards and Technology, October 1995.

1.6 MODEL CODE AGENCIES AND STANDARDS

Model code agencies are agencies whose codes are widely adopted to regions in the United States. The following is a partial list of code agencies and provisions in the United States that include seismic provisions. These documents are not considered to be a part of this recommended practice except as referenced elsewhere in this recommended practice.

a) *National Building Code*, Building Officials and Code Administrators International (BOCA).

b) *Uniform Building Code*, International Conference of Building Officials (ICBO).

c) *Standard Building Code*, Southern Building Code Congress International (SBCCI).

1.7 INDUSTRY CODES AND STANDARDS

The following are guidelines for specific design and construction practices that may be used in the seismic design or assessment of specific installations. These documents are often created, by consensus agreement, by professional organizations. These documents are not considered to be a part of this recommended practice except as referenced elsewhere in this recommended practice.

a) **American Concrete Institute (ACI)**
   (1) ACI 313, *Recommended Practice for the Design and Construction of Concrete Bins, Silos, and Bunkers for Storage of Granular Materials*
   (2) ACI 318, *Building Code Requirements for Reinforced Concrete and Commentary*
   (3) ACI 349, *Code Requirements for Nuclear Related Structures*
   (4) ACI 530, *Building Code Requirements for Masonry Structures*
   (5) ACI 530.1, *Specifications for Masonry Structures*

b) **American Institute of Steel Construction (AISC)**
   (1) *Manual of Steel Construction - Allowable Stress Design*
   (2) *Load and Resistance Factor Design Specification for Structural Steel Buildings*

c) **American Iron and Steel Institute (AISI)**
   (1) *Criteria for Structural Application of Steel Cable for Buildings*
   (2) *Specification for the Design of Cold-Formed Steel Structural Members*

d) **American National Standards Institute (ANSI)**
   (1) ANSI B31.3, *Chemical Plant Refinery Petroleum Piping*
   (2) ANSI B31.4, *Liquid Petroleum Transportation Piping Systems*
   (3) ANSI B31.8, *Gas Transmission and Distribution Piping Systems*

e) **American Petroleum Institute (API)**
   (1) API 650, *Welded Steel Tanks for Oil Storage*
   (2) API 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

f) **American Society of Civil Engineers (ASCE)**
   (1) ASCE 7, *Minimum Design Loads for Buildings and Other Structures*
   (2) ASCE 8, *Specification for the Design of Cold-Formed Stainless Steel Structural Members*
   (3) *Guidelines for the Seismic Design of Oil and Gas Pipeline Systems,* Committee on Gas and Liquid Fuel
   (4) *Guidelines for Seismic Evaluation and Design of Petrochemical Facilities,* Tash Committee on Seismic Evaluation and Design of Petrochemical Facilities

g) **American Society of Mechanical Engineers (ASME)**
   (1) *Boiler and Pressure Vessel Code*
   (2) ASME A17.1, *Safety Code of Elevators and Escalators*

h) **American Society for Testing and Materials (ASTM)**
   (1) ASTM D32.99, *Standard Specification for Filament-Wound Glass-Fiber-Reinforced Thermoset Resin Chemical-Resistant Tanks*

(2) ASTM C635, *Standard Specification for the Manufacture, Performance and Testing of Metal Suspension Systems for Acoustical Tile and Lay-in Ceiling Panels*
(3) ASTM C636, *Standard Practice for the Installation of Metal Suspension Systems for Acoustical Tile and Lay-in Ceiling Panels*

i) **American Water Works Association (AWWA)**
(1) AWWA D100, *AWWA Standard for Welded Steel Tanks for Water Storage*
(2) AWWA D110, *AWWA Standard for Wire-Wound Circular Prestressed-Concrete Water Tanks*

j) **Applied Technology Council (ATC)**
(1) ATC-14, *Evaluating the Seismic Resistance of Existing Buildings*
(2) ATC-3-06, *Tentative Provisions for the Development of Seismic Regulations for Buildings*
(3) ATC-33.03, *Guidelines for the Seismic Rehabilitation of Buildings*

k) **Federal Emergency Management Agency (FEMA)**
(1) FEMA 154 / ATC-21, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*
(2) FEMA 155 / ATC-21-1, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation*
(3) FEMA 172, *NEHRP Handbook for the Seismic Rehabilitation of Existing Buildings,* Building Seismic Safety Council
(4) FEMA 178, *NEHRP Handbook for the Seismic Evaluation of Existing Buildings,* Building Seismic Safety Council
(5) FEMA 222, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings - Provisions,* Building Seismic Safety Council
(6) FEMA 223, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings - Commentary,* Building Seismic Safety Council
(7) FEMA 74, *Reducing the Risks of Nonstructural Earthquake Damage*

l) **Institute of Electrical and Electronic Engineers (IEEE)**
IEEE Standard 344, *Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*

m) **National Fire Protection Agency (NFPA)**
NFPA-13, *Standard for the Installation of Sprinkler Systems*

n) **Rack Manufacturer's Institute (RMI)**
Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks

o) **Risk Management and Prevention Program (RMPP) Committee**
Proposed Guidance for RMPP Seismic Assessments

p) **Sheet Metal and Air Conditioners National Association (SMACNA)**
(1) *HVAC Duct Construction Standards, Metal and Flexible*
(2) *Rectangular Industrial Duct Construction Standards*
(3) *Guidelines for Seismic Restraint of Mechanical Systems and Plumbing Piping Systems*

q) **Steel Joist Institute**
Standard Specification Load Tables and Weight Tables for Steel Joists and Joist Girders

r) **Structural Engineers Association of California**
Recommended Lateral Force Requirements and Commentary

s) **United States Department of Defense**
   (1) Tri-Service Manual TM 5-809-10, *Seismic Design for Buildings*
   (2) Tri-Service Manual TM 5-809-10-1, *Seismic Design Guidelines for Essential Buildings*
   (3) Tri-Service Manual TM 5-809-10-2, *Seismic Design Guidelines for Upgrading Essential Buildings*

t) **United States Department of Energy**
   DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*

u) **United States Nuclear Regulatory Commission**
   (1) Generic Letter 87-02, *Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46*
   (2) *Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment,* Winston & Strawn, et. al.
   (3) NRC Regulatory Guide 1.60, *Design Response Spectra for Seismic Design of Nuclear Power Plants*

1.8 OTHER REFERENCES

The following are other documents referenced in this recommended practice. These documents are not considered to be a part of this recommended practice except as referenced elsewhere in this recommended practice.

a) Technical Report NCEER-93-0022, *Seismic Vulnerability of Equipment in Critical Facilities: Life-Safety and Operational Consequences,* K. Porter, et.al., National Center for Earthquake Engineering Research, November 24, 1993.

b) *Seismic Reliability Assessment of Critical Facilities*: *A Handbook, Supporting Documentation, and Model Code Provisions,* G. S. Johnson, et.al., Part A - Handbook, prepared for the Multidisciplinary Center for Earthquake Engineering Research, February, 1999.

c) *Seismic Reliability Assessment of Critical Facilities*: *A Handbook, Supporting Documentation, and Model Code Provisions,* G. S. Johnson, et.al., Part B - Supporting Documentation, prepared for the Multidisciplinary Center for Earthquake Engineering Research, February, 1999.

CHAPTER 2
IDENTIFICATION OF CRITICAL SYSTEMS AND COMPONENTS

2.1 INTRODUCTION

This chapter of the handbook describes the identification and documentation of critical systems and components which should be evaluated to assess the reliability of essential facility functions following an earthquake.

2.2 EVALUATION CONCEPTS

a) **Essential Facility Function.** A facility may have specific functionality requirements during or following an earthquake, as specified by federal law or federal, state, or local regulators. For examples, hospital performance requirements for critical care may be specified in a state-issued license; data processing requirements for banks may be specified in Federal law. In addition, a facility owner may determine that a function is essential if it is deemed financially important for continued operation or business recovery.

b) **Critical System**. A critical system is one that is required to provide either (i) the essential facility function, as defined above, or (ii) life-safety protection as required by other laws or regulations.

c) **Critical System Component**. A component of a critical system could be either a particular equipment item; a portion of a system such as piping, ducting, etc.; or a human action that is required to provide function of the critical system.

d) **Critical System Diagram**. These diagrams are one method to provide a pictorial view of system interrelationships and dependencies. As used in this Recommended Practice, the diagrams are a type of logic tree which used "AND" and "OR" logic to express system requirements to provide for the overall successful function of the facility.

2.3 IDENTIFICATION OF ESSENTIAL FUNCTIONS

Essential functions are those which must be provided by a facility during an earthquake, immediately following an earthquake, or within a specified time period following an earthquake. Examples may include requirements to provide emergency or critical care for hospitals or money transfers for banks.

Essential functions may be identified by any of the following means:

a) Specific facility performance requirements that are unique to a given facility, industry, or type of installation, may be specified by law or other regulatory or licensing requirements, under federal, state, or local jurisdiction.

b) Minimum standards of life-safety protection must be maintained irrespective of the event that has occurred and the level of escalation. This would include fire detection and alarm, fire response, building evacuation and egress, and similar systems or functions, as required by federal, state, or local laws and regulations.

c) A facility owner or manager may identify any additional function as critical and evaluate systems using this Recommended Practice because of financial considerations or any other reasons. Examples of such considerations would be concerns for capital costs, business interruption, and damage and recovery costs.

2.4 IDENTIFICATION OF CRITICAL SYSTEMS

As discussed above, critical systems are likely to include both life-safety systems and business operation systems. Life-safety systems are usually defined as those functions whose failure results in conditions where lives are in imminent danger or are not sufficiently protected from potential dangers. Typical examples of life safety functions are:

a) Fire response (including detection, suppression, and smoke barriers/purge)

b) Shutoff of hazardous material releases (primarily natural gas)

c) Elevator safety

d) Evacuation/Egress

Business operation systems are defined as those systems which must function in order to continue operation of the facility at full or reduced capacity. This definition of capacity is the starting point for the identification of the critical business operation functions. For example, operation of elevators may be considered to be essential for full building operation in one situation but non-essential for another similar building if the desired state is limited operation. This designation depends on the essential function of the facility, and is determined as the first step of the evaluation. Typical examples of business operation functions are:

a) Lighting/Power (including lighting, normal building power, emergency power)

b) Water Supply/Waste Removal (including water supply, sewage removal)

c) Storm Drainage

d) Normal Personnel Transport (including elevators)

e) Building HVAC (including heating, ventilation, air conditioning, HVAC control)

f) Communications (including telephone/communications, data telecommunications)

g) Data Processing (including data processing equipment, computer equipment)

h) Refrigeration

i) Gas Supply

j) Structural Concerns (including raised access floors)

Table 2-1 shows a multi-page checklist from Reference 1.8b that can be used to identify and document systems which are candidates for critical systems. The reviewer should examine each system identified in the table (**Bolded** items in far left column) and make a determination as to whether the system is a life safety system, business operation system, a non-critical system, or the system is not applicable to the facility in question.

If a system is determined to be critical (i.e., either a life safety or business operation system) the evaluator should define what the critical system encompasses. This definition serves to identify both what is considered as success and to help establish the bounds of the evaluation. A space is provided in Table 2-1 for definition of the requirements for each critical system. The evaluator should make this definition as clear and concise as possible at this stage. For example, the definition for the Gas Shutoff System could read something like the following: "The gas shutoff system is required to close the gas shutoff valve, either manually or automatically, following the earthquake."

Table 2-1 also identifies sub-systems (indented items beneath each System) which serve to better define the boundaries of the main system. Each of these sub-systems should be examined and a determination made in the same manner as for the main systems. Additional spaces are included if other important systems or sub-systems are identified.

2.5 IDENTIFICATION OF COMPONENTS

Functionality of the critical systems identified in the previous section is generally provided by operation of combinations of equipment and/or human actions. In some cases, a single operator action may be all that is required in order to provide for functionality, while in other cases the combined operation of several systems may be required. In some cases there may be redundant means for providing full or partial operation.

The goal of the entire process of identification of components is to narrow the scope of components examined from an all-encompassing list of building equipment to a list which reflects only those components necessary to provide functionality of critical systems while also accounting for any enhanced safety provided by installed redundancy. This section describes the method to be used to complete a systematic equipment identification process.

a) Component Identification Worksheet

One method for the identification of critical system equipment uses a worksheet. Table 2-2 is a general worksheet for one of the typical critical systems identified in Section 2.4. Reference 1.8b provides additional worksheets for other systems, as well as a blank worksheet to be completed if additional functions are identified or as a continuation sheet for any of the other worksheets. The types of information to be identified in each worksheet are discussed in detail below. In all the examples, Table 2-2 is referenced, but the discussion is equally applicable to any of the other tables.

(1) *Definition of System* - The starting point for this identification of components is the refinement of the definition of what the critical system of interest encompasses and the specific performance requirements of that system. This definition serves to identify both what is considered as success and to establish the bounds of the evaluation. If the definitions established during the identification of critical systems are sufficient to accomplish these goals, a reference to the worksheet in Table 2-1 is all that is required. Otherwise, for each identified critical system, the definition should identify the following:

i) The main system, systems or portion of systems which provide the required function,

The performance requirements and specific required functions of the items identified in item 1 (i.e., operation, integrity)

ii) How the function is provided (i.e., automatic or manual)

iii) When that function is required and for what duration

(2) *Identification of Specific Components* - Once the system requirements are established, the reviewer then starts the task of identifying specific equipment which must function or maintain integrity in order to successfully accomplish the required system function. A component identification sheet, as shown in Table 2-2, will have a basic list of components typically associated with each sub-system. The reviewer should examine each item on the list and determine the criticality of each component. The categories of criticality are:

i) **Essential (E).** Component is required to perform its function in order for the critical system to perform its required function (i.e., no other component can provide the same function)

ii) **Redundant (R).** Component is one of two or more components which can provide a function in order for the critical system to perform its required function (i.e., any redundant component can provide the same function)

iii) **Non-Essential (N).** Component is not required in order for the critical system to perform its required function. This category should also be used if a listed component is not installed in the system being examined.

If a component is determined to be redundant to another component, the redundant component item number should be identified and listed in the appropriate column on the form. For example, in Table 2-2 under "A. Detection", any type of detectors which will result in the desired response (e.g., alarm, sprinkler actuation, etc.) should be identified as redundant to each other in the list.

(3) *Support Requirements* - The final piece of component specific information necessary in the identification of essential components is the determination of support requirements, if any, for each piece of equipment. Support requirements generally deal with such functions as power, cooling water, or some types of actuation. The systems which provide these support functions are identified as support systems. In each of the critical system definition sheets, all of the components which provide the support functions could be added in their entirety and the overall resultant list of components would be correct. However this would result in a significant amount of repetition and is not efficient. Rather support systems should be added as a separate critical system (unless already required elsewhere as a critical system) and the support system components included on a "generic" form of Table 2-2. The one exception to this process is in the case where a support system or a certain portion of a support system only provides support to one critical system. In these cases, it is better to include it with its associated critical system. For example, an uninterruptible power supply (UPS), while considered to be a part of the electric power system, may only power a computer system. It can be considered a redundancy for the power requirements of the computer system but not for any other equipment which requires power. In this case the UPS should be listed with the specific equipment for the critical system and the electric power system identified as a support system.

(4) *Other Considerations* - Two general items are important in determining the potential for equipment to reliably provide service as required. Questions associated with these general items are included for each sub-system on each sheet. The responses to these questions may impact whether or not a component is credited for the system functionality. These questions are:

i) Is operator intervention required for operation of any of the above equipment? If yes, is the area expected to be accessible?

ii) Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures?

For the first question, if operator action is required to operate the equipment, but the area is not likely to be accessible following an earthquake, the component should not be credited. If this piece of equipment is redundant to something else, this results in a loss of redundancy but not failure of the critical system. If however, this item is essential, the critical system would be considered to be failed by the earthquake and possible changes may be in order to provide some redundancy or to ensure accessibility.

For the second question, if a component, system, or portion of a system has historically been unreliable due to failures or high maintenance requirements the reviewer may not want to include the component, system or portion of a system except as a redundancy. If components which fit in this category are to be credited, either as essential components or redundant components, the associated component score should be modified to account for the reduced reliability.

b) Support System Cross Reference

In order to ensure that all support requirements are fully addressed, Table 2-3, Support System Component Identification Cross Reference, should be completed in conjunction with each component identification worksheet (e.g. Table 2-2). Whenever a support function is identified to be required, the reviewer should add the support function to Table 2-3 including the definition and where it was identified. Once an component identification worksheet has been completed for a support system, the reference should also be added to Table 2-3. In this manner the reviewer can ensure that all appropriate components are included.

2.6 DOCUMENTATION

This section presents a recommended method for documentation of systems and components for use with this Recommended Practice. Additional discussion can be found in Reference 1.8b.

a) Critical Systems Diagrams. These diagrams provide a pictorial view of the system interrelationships identified in the previous sections and provide a framework for quantifying the relative reliability of the systems following an earthquake using the methods described in Chapters 3 and 4 of this recommended practice. They are also a useful tool for the process of making practical risk management decisions, as discussed in Chapter 5.

The critical system diagrams are a type of logic tree which uses "AND" and "OR" logic to express the system interrelationships to the overall successful functioning of the building being examined. The following sections describe the method used to develop these critical system diagrams.

b) Logic Trees. The logic trees are success oriented and are built using "AND" and "OR" logic gates. An "AND gate is defined as being successful if all the inputs to the gate are successful. An "OR" gate is defined as being successful if any one of the inputs are successful. By combining these logic gates the reviewer can develop a model which accurately represents the critical system needs following an earthquake and can be used to identify the components which most critically affect the ability to provide these critical functions. All of the information necessary to build this logic model is collected as discussed in the previous sections. The development of the logic model should be completed in a step-by-step manner with each level of the logic tree being completed before proceeding to the next level. This methodical approach helps to ensure that all necessary functions and components are included and that the function and component dependencies are accurately addressed.

c) Essential Functions. The logic trees begin with a top event which represents successful functioning of the facility following an earthquake. This top event is labeled with the facility name and is an "AND" gate with two inputs, Life Safety Functions and Business Operations Functions. The "AND" gate implies that both functions must be provided in order for the successful provision of the critical functions. An example of this top level logic is shown in Figure 2-1. Each of these events represent a gate in the logic diagram and will be further developed in the manner discussed below either on the same page of the model or as a top event which is shown on another page. Care should be taken to ensure that if an event is developed on another page that there is a clear indication of where such development takes place.

If additional emphasis is desired for some other function such as Telecommunications Equipment or Data Processing Equipment they can also be included as a separate input to the "AND" gate rather than being included under one of the other items. By including them at this level, their overall importance is visually seen at the top level of the model. This positioning at the top level will not impact the results of the model evaluation. An example of two equivalent top level logic diagrams is shown in Figure 2-2. Each of these inputs to the top gate is developed further in a step-by-step process until the boxes placed under a gate represent components rather than functions.

d) Critical Systems. The next level of the logic model is developed from the information previously gathered and summarized in Table 2-1. For example, the systems which are marked as Life Safety in Table 2-1 become inputs to an "AND" gate in the top logic for Life Safety Functions. The systems which are marked as Business Operations in Table 2-1 become inputs to an "AND" gate in the top logic for Business Operations Functions. Again, these are both "AND" gates since each of the functions must be provided in order to successfully provide the required essential functions. In some cases in Table 2-1, a system may be listed as both a Life Safety and Business Operations system. In these cases the system should be included in both places. The lower level development of the logic will address any differences in sub-systems between the two locations. Any of the systems which include sub-systems should be represented as an "AND" gate with each of the applicable sub-systems as inputs. Figure 2-3 shows an example of the first input level to the Life Safety gate and the sub-system inputs for the Fire Response system gate.

e) Specific Components. Up to this point, all of the logic in the tree consists of "AND" gates since the primary focus has been on the function level and the basis of the definition of the functions has been to include only the essential functions. The remaining portions of the tree will define which components and in what combinations these components will adequately provide the functions. This is the level at which the concept of redundancy in design is generally implemented. It is this redundancy which leads to slightly more complexity in the modeling process. Worksheets such as in Table 2-2 identify the equipment necessary to provide the specific functions for that building.

For each sub-system there may be one or more categories of components. For example, in Table 2-2, Fire Response Sub-system Detection and Alarm is divided into three categories, Detection, Alarms, and Detection/Alarm Interface. If all three of these categories are required the Sub-system is an "AND" gate with each of these categories as an input. Within a category, all, one, or several of the listed components may be required for success.

The important equipment identified in these tables for each category have been previously defined in the table as being essential or redundant. In general, components which are categorized as essential are included as inputs to an "AND" gate which defines the category. If a category has only one essential component associated with it, a gate is not required and the equipment is shown as an input to the sub-system gate.

f) Redundant Components. If equipment is categorized as redundant, it and its redundant components are included as inputs to an "OR" gate which defines the category. The case may occur in which several of the components are essential and others are redundant. In this case the essential components are treated in the same manner as described above. In addition, a separate "OR" gate is added to the "AND" gate and the redundant components are input to the "OR" gate. Figure 2-4 illustrates the development of the fire Detection and Alarm sub-system logic.

g) Support System Requirements. These are identified in the tables in this chapter and are included at the level in the logic tree of the components it supports. An example of this is the case where a pump must system in order to provide fire water for fire suppression. In order to function, the pump must be provided with power. The way in which this dependency is included in the logic model is by including both the pump and its power supply as inputs to an "AND" gate at the same level as the pump would normally occupy.

The exceptions to this are if all components for a category require the same support system, or if a sub-system or system fail as the result of failure of the support system. In these cases it is acceptable to input the support system at the highest level in the logic model at which everything below it in the logic structure is also dependent upon the support system. Figure 3-4 shows an example of how support system requirements are included in the logic tree.

This process is repeated until logic models have been developed for each system/sub-system defined in the component identification worksheets prepared previously. Most support systems support multiple critical systems. The portion of the model associated with the support system need only be developed once and referred to at each place in the model in which it provides its support system.

Table 2-1
IDENTIFICATION OF CRITICAL SYSTEMS (1/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Fire Response	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Detection and alarm	☐	☐	☐	☐
Suppression	☐	☐	☐	☐
Air duct fire and smoke barriers	☐	☐	☐	☐
Smoke purge	☐	☐	☐	☐
Other:________	☐	☐	☐	☐
________	☐	☐	☐	☐
________	☐	☐	☐	☐
Gas Shutoff	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Other:________	☐	☐	☐	☐
________	☐	☐	☐	☐
________	☐	☐	☐	☐
Elevator Safety	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Detection/control	☐	☐	☐	☐
Other:________	☐	☐	☐	☐
________	☐	☐	☐	☐
________	☐	☐	☐	☐
Building/Evacuation Egress	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Alarm/indication	☐	☐	☐	☐
Available routes	☐	☐	☐	☐
Other:________	☐	☐	☐	☐
________	☐	☐	☐	☐
________	☐	☐	☐	☐

[1] **LIFE SAFETY**-Failure results in conditions where lives are in imminent danger or not sufficiently protected from potential dangers
[2] **BUSINESS OPERATIONS**-All other essential facility functions
[3] **NOT CRITICAL**-Function non-essential
[4] **NOT APPLICABLE**-Function not applicable to facility

Table 2-1 (continued)
IDENTIFICATION OF CRITICAL SYSTEMS (2/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Lighting/Power	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Lighting	☐	☐	☐	☐
Normal building power	☐	☐	☐	☐
Emergency power	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
Water Supply/Waste Removal	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Water Supply	☐	☐	☐	☐
Sewage Removal	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
Storm Drainage	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
Normal Personnel Transport	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Elevators	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐
____________	☐	☐	☐	☐
____________	☐	☐	☐	☐

[1] **LIFE SAFETY**-Failure results in conditions where lives are in imminent danger or not sufficiently protected from potential dangers
[2] **BUSINESS OPERATIONS**-All other essential facility functions
[3] **NOT CRITICAL**-Function non-essential
[4] **NOT APPLICABLE**-Function not applicable to facility

Table 2-1 (continued)
IDENTIFICATION OF CRITICAL SYSTEMS (3/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Building HVAC	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Heating	☐	☐	☐	☐
Ventilation	☐	☐	☐	☐
Air conditioning	☐	☐	☐	☐
HVAC control	☐	☐	☐	☐
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Communications	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Telephone/communications	☐	☐	☐	☐
Data telecommunications	☐	☐	☐	☐
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Data Processing	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Data processing equipment	☐	☐	☐	☐
Computer equipment	☐	☐	☐	☐
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Refrigeration	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐

[1] **LIFE SAFETY**-Failure results in conditions where lives are in imminent danger or not sufficiently protected from potential dangers
[2] **BUSINESS OPERATIONS**-All other essential facility functions
[3] **NOT CRITICAL**-Function non-essential
[4] **NOT APPLICABLE**-Function not applicable to facility

Table 2-1 (continued)
IDENTIFICATION OF CRITICAL SYSTEMS (4/4)

System / Sub-System	Life Safety [1]	Business Operations [2]	Not Critical [3]	Not Applicable [4]
Gas Supply	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Structural Concerns	☐	☐	☐	☐
Requirements of system				
Sub-Systems				
Raised access floors	☐	☐	☐	☐
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Other Critical Systems (define)				
________________	☐	☐	☐	☐
Requirements of system				
Sub-Systems	☐	☐	☐	☐
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
Requirements of system				
Sub-Systems	☐	☐	☐	☐
Other:________________	☐	☐	☐	☐
________________	☐	☐	☐	☐
________________	☐	☐	☐	☐

[1] **LIFE SAFETY**-Failure results in conditions where lives are in imminent danger or not sufficiently protected from potential dangers
[2] **BUSINESS OPERATIONS**-All other essential facility functions
[3] **NOT CRITICAL**-Function non-essential
[4] **NOT APPLICABLE**-Function not applicable to facility

Table 2-2
FIRE RESPONSE CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SYSTEM: FIRE RESPONSE

DEFINITION OF SYSTEM

___

___

___

SUB-SYSTEM: Detection And Alarm

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Detection					
A.1 Area/Spot Smoke Detectors	E	R	N		
A.2 Line Smoke Detectors	E	R	N		
A.3 HVAC/Plenum Smoke Detectors	E	R	N		
A.4 Heat Detectors	E	R	N		
A.5 Sprinkler Flow Sensors	E	R	N		
A.6 Pull Stations	E	R	N		
A.7 Other(define)	E	R	N		
___	E	R	N		
B. Alarms					
B.1 Bell/Siren Alarms	E	R	N		
B.2 Speakers	E	R	N		
B.3 Strobe Lights	E	R	N		
B.4 Remote Alarm Monitors (specify)	E	R	N		
___	E	R	N		
B.5 Other (define)	E	R	N		
___	E	R	N		
C. Detection/Alarm Interface					
C.1 Computer System	E	R	N		
C.2 Fire Communication Center	E	R	N		
C.3 Alarm Panel(s)	E	R	N		
C.4 Cabling/Conduit	E	R	N		
C.5 Other (define)	E	R	N		
___	E	R	N		

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ___
If yes, is the area expected to be accessible?

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ___
If yes, explain:

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table 2-2 (continued)
FIRE RESPONSE CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SUB-SYSTEM: Fire Suppression

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Manual Suppression					
A.1 Hand Extinguishers	E	R	N	________	________
A.2 Hose Stations	E	R	N	________	________
A.3 Hose Station Water Supply (if different from Automatic System)	E	R	N	________	________
A.4 Other(define)	E	R	N	________	________
________	E	R	N	________	________
B. Automatic Suppression - Water					
B.1 City Water Supply	E	R	N	________	________
B.2 On-site Water Supply	E	R	N	________	________
B.3 Motor-Driven Fire Pump(s)	E	R	N	________	________
B.4 Diesel Driven Fire Pump(s)	E	R	N	________	________
B.4.a Diesel Start System	E	R	N	________	________
B.4.b Diesel Day Tank	E	R	N	________	________
B.4.c Diesel Piping/Valves	E	R	N	________	________
B.4.d Diesel Aux Fuel Supply	E	R	N	________	________
B.5 Fire Water Feed Main	E	R	N	________	________
B.6 Fire Water Cross Mains	E	R	N	________	________
B.7 Fire Water Branch Lines	E	R	N	________	________
B.8 Fire Water Risers	E	R	N	________	________
B.9 Sprinkler Heads	E	R	N	________	________
B.10 Deluge/Alarm Valves	E	R	N	________	________
B.11 Other (define)	E	R	N	________	________
________	E	R	N	________	________
C. Automatic Suppression - Gas					
C.1 Gas Storage (Halon/Other)	E	R	N	________	________
C.2 Connection to Detectors	E	R	N	________	________
C.3 Other (define)	E	R	N	________	________
________	E	R	N	________	________

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ________
If yes, is the area expected to be accessible?

____

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ________
If yes, explain:

____

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table 2-2 (continued)
FIRE RESPONSE CRITICAL SYSTEM COMPONENT IDENTIFICATION WORKSHEET

SUB-SYSTEM: Air Duct Fire and Smoke Barriers

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Fire and Smoke Barriers					
A.1 Fire and Smoke Dampers	E	R	N	______	______
A.4 Other(define)	E	R	N	______	______
______	E	R	N	______	______

B. General Items

B.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

______

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

B.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

______

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

SUB-SYSTEM: Smoke Purge

	Criticality (circle one) E-essential, R-redundant, N-non-essential			Redundant Component List redundant item number	Support System Required List function (i.e., power, cooling water, etc.)
A. Detection					
A.1 Fire Control Center Panel	E	R	N		
A.2 Other(define)	E	R	N	______	______
______	E	R	N	______	______
B. Pressurization					
B.1 Fans	E	R	N	______	______
B.2 Actuation	E	R	N	______	______
B.3 Other (define)	E	R	N	______	______
______	E	R	N	______	______
C. Purge Pathway					
C.1 Break Window System	E	R	N	______	______
C.2 Other (define)	E	R	N	______	______
______	E	R	N	______	______

D. General Items

D.1 Is operator intervention required for operation of any of the above equipment? (Y/N) ______
If yes, is the area expected to be accessible?

______

(Note: if the area is not accessible, equipment requiring manual operation should not be credited.)

D.2 Based on experience, has any of the identified equipment required an above average amount of maintenance or been inoperable or degraded for a significant amount of time due to failures? ______
If yes, explain:

______

(Note: if the equipment is highly unreliable, it should not be credited except as a possible redundancy.)

Table 2-3
SUPPORT SYSTEM COMPONENT IDENTIFICATION CROSS REFERENCE

No.	Support Function	Description	Equipment ID Where Identified?	Equipment ID Form Developed For Support Function
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

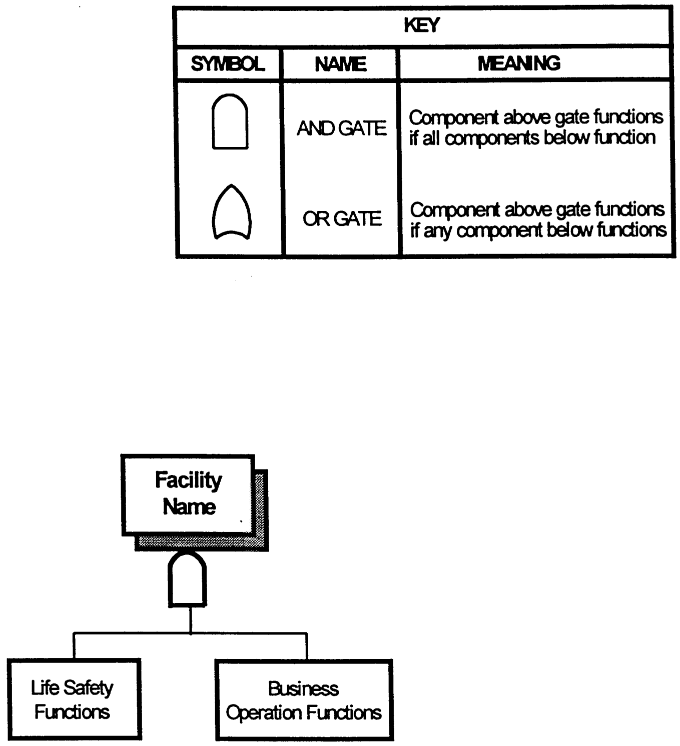


Figure 2-1: Facility Top Logic Model

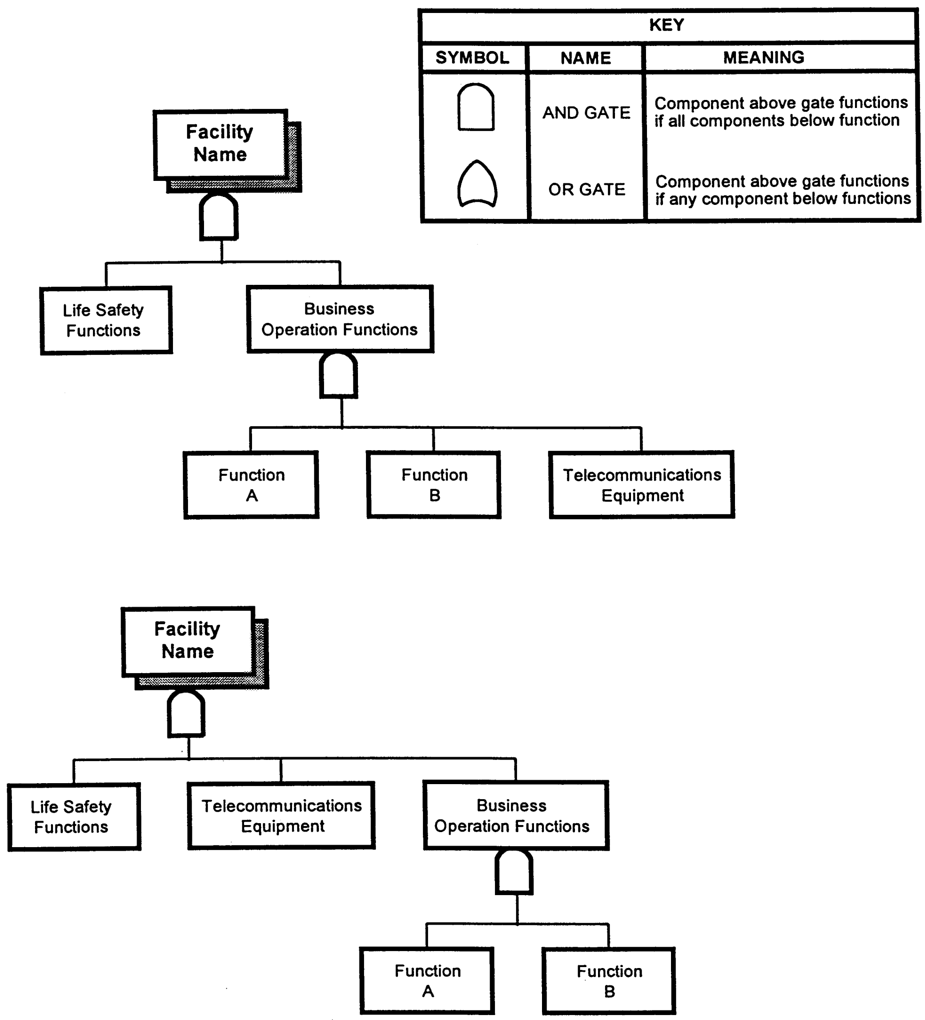


Figure 2-2: Equivalent Logic Model Configurations

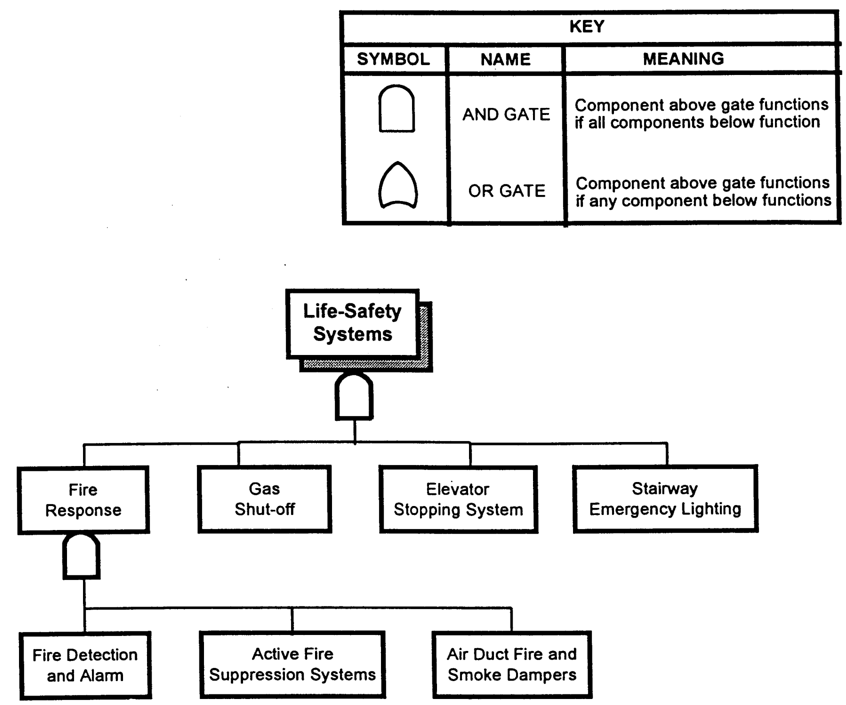


Figure 2-3: Life-Safety Systems/Fire Response Level Logic

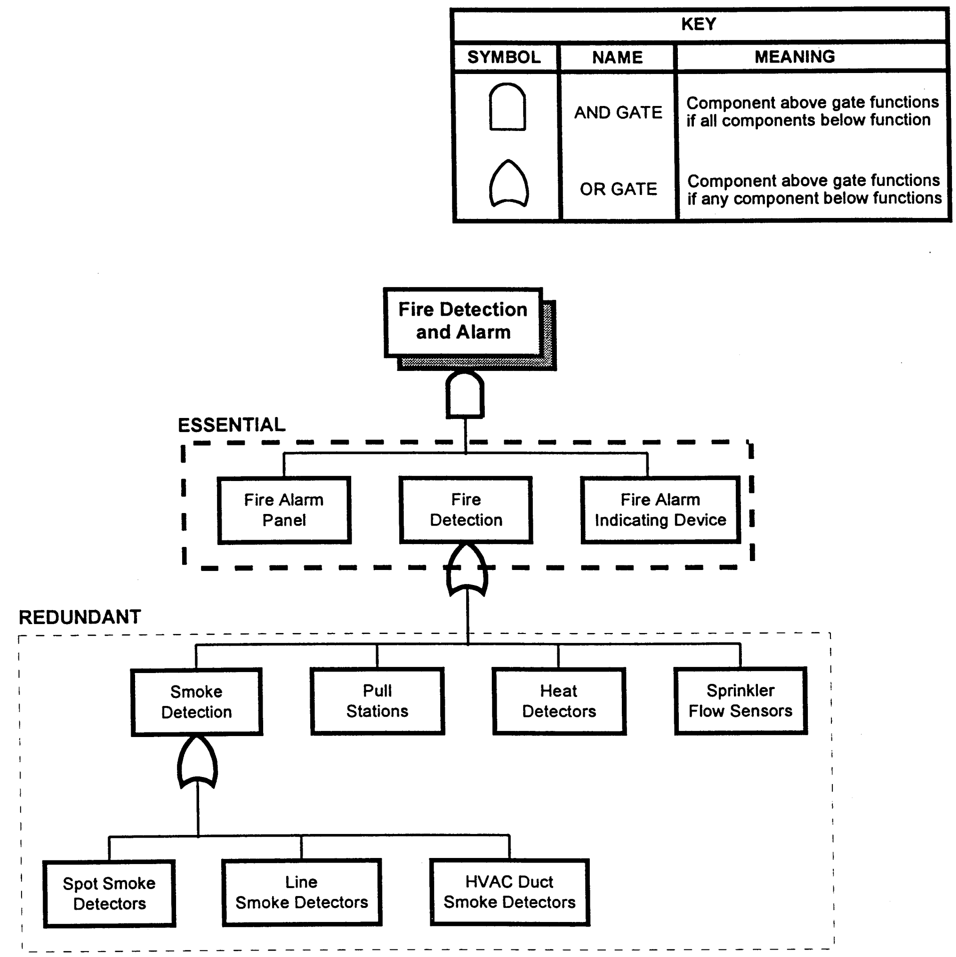


Figure 2-4: Fire Detection and Alarm Logic Example

CHAPTER 3
COMPONENT EVALUATION

3.1 INTRODUCTION

A standard method of evaluating individual equipment system components is needed to achieve risk reductions as promoted in this recommended practice. This method can be used by an individual to identify and prioritize vulnerabilities on simple score sheet, considering the seismic hazard to which the facility is exposed.

Section 2 has described the identification and documentation of important systems and components to be evaluated. The following sections describe a step-by-step approach for component evaluation.

a) Section 3.2 explains the basic concepts used in component evaluation in this chapter.

b) Section 3.3 describes the method of selecting score sheets for individual equipment items.

c) Section 3.4 describes the methods for identifying the seismic hazard for the facility and the method for incorporating location in a building.

d) Section 3.5 describes how to select the basic score for an equipment item.

e) Section 3.6 describes how to incorporate specific conditions of the equipment item being assessed into the component score.

f) System 3.7 describes how to determine the overall score for the component being evaluated.

3.2 EVALUATION CONCEPTS

a) **Screening Assessment**. The component evaluation methodology described in this recommended practice is a screening assessment. It is intended for rapid use to identify obvious problems that require immediate attention and to provide a method of prioritizing potential upgrades and more detailed analyses. As such, the data sheets and other methods presented in this Chapter may not address all situations that might be encountered in the course of component evaluation. The individual must use sound judgment in documenting other perceived vulnerabilities and adverse conditions and including them in the evaluation.

b) **Functional Failure**. The intent of the methodology for component evaluation is to identify potential causes of functional failure, i.e., reasons why the component would not be able to perform its required function after an earthquake. It is not intended to identify or preclude all causes of damage, where that damage does not affect function of the component.

c) **Weak Links**. This methodology is intended to focus on weak links, or critical vulnerabilities, as proven by historic earthquake performance of similar components. It is not intended to be a thorough, rigorous component analysis or test program.

d) **Seismic Hazards**. This methodology incorporates seismic hazards into the assessment in terms of site seismicity and location in building. Because this is intended for general use, the method is based on use of measures of regional seismicity, such as described in applicable governing building codes. These data are publicly available and easily obtained by any individual. This does not preclude individuals from using any more detailed information available on site seismicity, local soil conditions, or other conditions that would affect seismic response of the components.

e) **Relative Reliability**. Component scores that are computed are intended to be used as a measure of relative reliability, when comparing to other components and other systems. Although there is some quantitative relation to probability of failure, the values should not be interpreted as the results of rigorous calculations of failure probability.

3.3 SELECTION OF DATA SHEETS

For each of the major system components identified in the analysis of Chapter 2, a component assessment should be performed. The method for component assessment in this recommended practice uses component data sheets, similar to those found in the Handbook referenced in Section 1.8b. Those data sheets are intended to address major components found in key equipment systems in critical facilities, as documented in Reference 1.8a.

Selection of data sheets should be obvious for most major electrical and mechanical equipment items. However, data sheets have not been developed for every possible equipment item or configuration of equipment. Data sheets may also not be available for unique items that are specific to a given industry. In addition, particular industries may use certain equipment items that have been adapted to that industry in a way that could affect the response to earthquake loads. In selecting data sheets, the following should be considered:

a) Equipment items should be considered similar to those on data sheets if they have the same general characteristics as that equipment and would be expected to respond in a similar manner to earthquake loading. The characteristics that should be considered include general construction, anchorage, mass distribution, typical size, typical aspect ratio (height to width), and functional requirements.

b) The individual should be aware of differences in the equipment, especially with regards to reasons why the equipment being evaluated may be more sensitive to earthquake shaking than the equipment considered in the data sheets. This includes internal components, such as electrical subcomponents that may short out the equipment due to rocking, relays or switches that could cause the equipment to cease functioning, or control boards that can detach and slide. Any such differences should be identified, and documented as described in Section 3.6.

c) The individual should also consider whether the design was similar for the component being evaluated and the typical components for which data sheets are provided. For example, the individual should determine whether the components are typically engineered for seismic loads, whether they are tested for shaking, whether they are sensitive to shaking in the frequency range typical of earthquakes, and whether anchorage is engineered for seismic loads.

d) When using a different data sheet than provided for a specific class of equipment, the individual should assess the appropriateness of the modification factors, as described in Section 3.6, and make appropriate adjustments. For example, if the item being assessed is more sensitive to impact from falling objects than the data sheet component, that factor may be increased to account for that effect.

3.4 SEISMIC HAZARD AND BUILDING LOCATION

Figure 3-1 shows an example data sheet from Reference 1.8b. The first step in component assessment is to identify the seismic load level that the component is expected to experience. This is a function of the regional seismicity, expressed in terms of the seismic zone, and the location in the building. The matrix in the data sheet is used to assign a load level classification to account for both of these features. The following should be considered when using this matrix.

a) Seismic zone refers to the classification applied by local regulating authorities to describe the seismicity at the facility location. These are generally found in model codes that are adopted by a locality, such as discussed in Section 1.6. The zones are referenced to the two most common zonations for the United States, from the Uniform Building Code (UBC), found in Reference 1.6b, and the Provisions from the National Earthquake Hazard Reduction Program (NEHRP), which are found in Reference 1.7k(5). The NEHRP provisions have been adopted by model code agencies and other industry standards and are now used in many parts of the country. Maps showing both of these zonations are also provided in Reference 1.8b.

b) If the individual has specific data on the site, such as site seismicity from a hazards analysis, or local soil conditions, that may affect seismic response of equipment components, that data may be incorporated into the component evaluation by a modification of the effective zone and seismic load level classification. To properly make such modifications, the individual should understand the derivation of those load level classifications, as described in Reference 1.8c.

c) Location in the building is relative to the overall height of the building, measured generally in terms of lower 1/3, middle 1/3, and upper 1/3. Some judgment should be applied, such as considering the location of the attachment of the component to the building structure. The height of the building should be considered the height of the portion of the building containing the component, as measured from the top of foundation to the roof.

3.5 BASIC SCORES

As shown in Figure 3-1, a basic score is provided for each of the load level classifications. The basic score in the appropriate column should be circled on the data sheet.

3.6 PERFORMANCE MODIFICATION FACTORS

As shown in Figure 3-1, several potential vulnerabilities have been identified for each general type of component, with a relative effect on reliability quantified in terms of a performance modification factor (PMF). The next step in the evaluation process is to identify which PMFs are applicable to the specific component being evaluated. The individual should use the column on the score sheet for the appropriate seismic load level classification, the same as used for the basic score. The values assigned to **all** applicable PMFs should be circled in that column. It is critical that the evaluator not simply evaluate for the worst-case PMF and then stop the evaluation process. All PMFs should be evaluated and applicable PMFs identified for use in Risk Management, as described in Chapter 5. The following should be considered when performing this evaluation:

a) Guidance is provided on the data sheet and in the Handbook (Reference 1.8b) as to the intent of the PMF. If there is any doubt as to the applicability, the reviewer should circle the PMF so that it can be evaluated later in more detail.

b) When lacking data due to inaccessibility, lack of drawings, or other reasons, the reviewer should make the most conservative assumptions with regards to identifying applicable PMFs. The reason for the conservative assumption should be noted on the data sheet so that those PMFs can be reassessed with better data if necessary.

c) The PMFs identified during this phase of the evaluation can be changed or neglected later, as described in the risk assessment tasks of Chapter 5. Any unsubstantiated assumptions should be documented and reviewed for appropriateness and importance.

d) Data sheets, such as in Figure 3-1, typically will have a PMF marked as other, without associated values or specific issues identified. This is a caution that it is impossible to cover all possible conditions with meaningful PMFs. For example, severely corroded connections on a component may lead the reviewer to question the capability of a component to survive earthquake loading. The user must exercise some judgment as to the amount of weight to put on each of these concerns and assign a value accordingly. Additional guidance is provided in Reference 1.8b.

e) It should be remembered that PMFs will always **reduce** the total score.

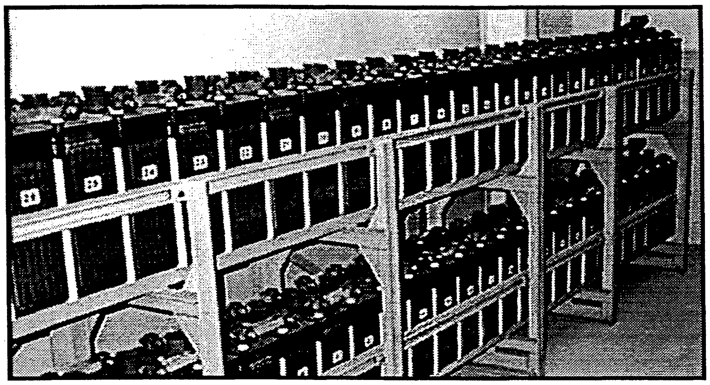
3.7 CALCULATION OF COMPONENT SCORES

The total score for a component is calculated by subtracting the worst case PMF from the basic score. That value is then used in the systems analysis, as described in Chapter 4. The reviewer should note the following:

a) Because all applicable PMFs have been identified, the total score is subject to change as more refined analyses are performed, upgrades are performed, or systems are modified, as discussed in Chapter 5. If it is determined that a PMF should be reduced, or neglected, the total score may be recalculated, subtracting the largest of the remaining applicable PMFs from the basic score.

b) A relatively low component score does not necessarily indicate that an upgrade will be required. The systems analysis, as described in Chapter 4, is intended to account for the importance of the equipment item, system redundancies, and other factors in quantifying system reliability. However, the reviewer may identify obvious sources of low scores that can be easily and inexpensively modified, such as replacement of missing nuts and bolts, or anchorage of equipment. Those items should be identified for consideration in the risk management tasks of Chapter 5.

Rapid Visual Screening Score Sheet | EL-06



ID Number ______________________

Comments ______________________

____

____

____

Earthquake Load Level (circle one letter)

			Location in Building		
	NEHRP	UBC	Bottom Third	Middle Third	Top Third
Z	1-3	1	A	A	A
O	4-5	2	A	B	C
N	6	3	B	C	D
E	7	4	C	D	E

Batteries and Racks

Scores and Modifiers - Batteries and Racks

(circle a Basic Score and **all** PMFs that apply - use the column indicated by the Earthquake Load Level above)

	Description	A	B	C	D	E
Basic Score		**6.0**	**5.5**	**5.1**	**4.6**	**4.2**
	1. No anchorage	2.2	2.2	2.2	2.2	2.2
	2. "Poor" anchorage	2.0	2.0	2.0	2.0	2.0
P	3. No battery spacers	2.2	2.2	2.2	2.2	2.2
M	4. No longitudinal cross-bracing	2.0	2.0	2.0	2.0	2.0
F	5. No battery restraints	2.4	2.4	2.4	2.4	2.4
	6. Interaction concerns	2.4	2.4	2.4	2.4	2.4
	7. Other ______________					
Final Score = Basic Score - **highest applicable** PMF						

Note that this is a screening process and is inherently conservative. If there is any question about an item, note it and select the appropriate PMF. See the following page for PMF guidelines.

Figure 3-1: Sample Data Sheet

Rapid Visual Screening Score Sheet | EL-06

Performance Modification Factors (PMFs)

1, 2 If there are no anchor bolts at the base of the frame, select PMF 1. If the anchors appear to be undersized, if there are not anchors for every frame of the rack, or if the anchorage appears to be damaged select PMF 2.

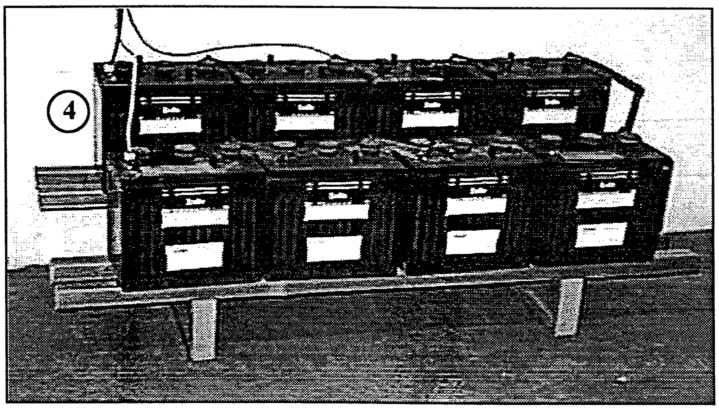
3 Look for stiff spacers, such as Styrofoam, between the batteries that fit snugly to prevent battery pounding. If there are none, select PMF 3.

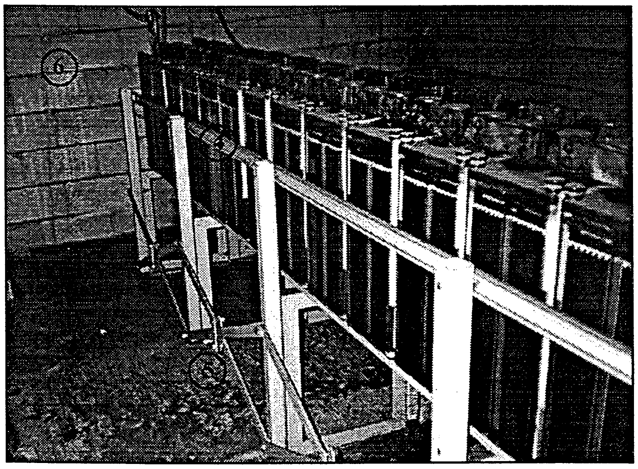
4 The rack should provide restraints to assure that the batteries will not fall off. The photo above shows a rack with no restraints, while the photo to the left shows a rack with restraints. Select PMF 4 if adequate restraint is not provided.

5 Racks with long rows of batteries need to be braced longitudinally as shown in the photo to the left. Select PMF 5 if no cross-bracing is present.

6 If large items such as non-structural walls could fall and impact the battery racks, select PMF 6.

7 For other conditions that the reviewer believes could inhibit battery function following an earthquake (e.g., a history of problems with this piece of equipment), assign a PMF value relative to the existing PMFs in the table. Add a descriptive statement for the concern.





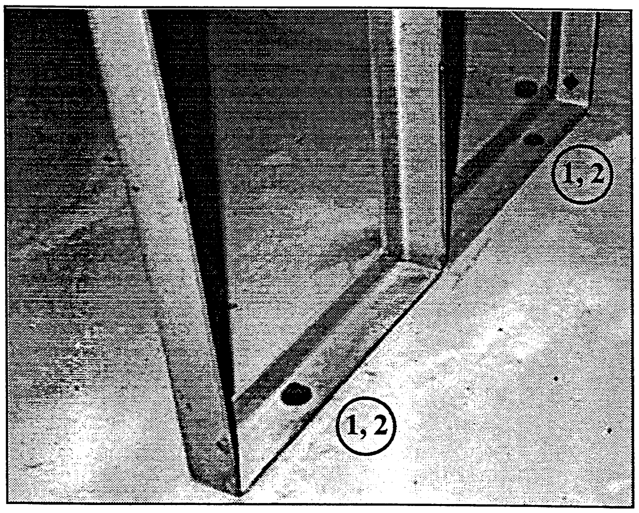


Figure 3-1: Sample Data Sheet

CHAPTER 4
SYSTEMS EVALUATION

4.1 INTRODUCTION

This chapter describes a standard method of generating system scores based on component evaluations. This method can be used by an individual to identify and prioritize vulnerabilities on a system and facility basis.

Chapter 2 has described the identification and documentation of important systems and components to be evaluated. Chapter 3 has discussed an approach for component evaluation. The following sections describe the systems evaluation methodology.

a) Section 4.2 explains the basic concepts used in systems evaluation.

b) Section 4.3 describes the method of calculating system scores from individual component scores.

4.2 EVALUATION CONCEPTS

a) **Redundancy**. The ability of a system to perform its function despite the failure of one or more components indicates redundancy in the system. This is a key element in the methodology described in this recommended practice. Although damage to a system is not desirable, it may not require mitigation if redundancy is present.

b) **Dependency**. Dependent systems require that all components remain functional for that system to perform its intended function. Failure of any component will result in system failure.

4.3 CALCULATION OF SYSTEM SCORES

For each of the major systems identified in the analysis of Chapter 2, a system evaluation should be performed. The methodology described in this recommended practice makes use of the system diagrams developed for each system and the component scores described in Chapter 3. The basis for generating system scores from component scores is presented in Reference 1.8c.

The procedure for calculating system scores is described below. An example using a hypothetical system and scores is contained in Figure 4-1.

a) **General rules.** The system diagrams developed according to the guidelines in Chapter 2 are used as the score sheets for their respective systems. System scores are calculated as follows:

(1) Assign the component score determined using the guidelines in Chapter 3 to the appropriate box on the system diagram.

(2) System scores are calculated by following the system diagram from the bottom to the top. The "and" and "or" gates indicate how the individual component scores are combined as the reviewer moves up the diagram. The final score for the system is the combination of all the individual component scores following the rules of this section and is recorded in the box at the top of the diagram.

(3) All components connected to an "and" gate are required to function, so that path is dependent. Only one of the components connected to an "or" gate is required to function, so that path is redundant. Rules for combining component scores in dependent and redundant systems are described below.

b) **Rules for redundant systems.** When a group of components is linked by an "**or**" gate (indicating redundancy), the recommended overall score for that group is the highest of the component scores (S_{max}) plus a factor (f). This factor depends on the number of redundant components (N) and takes the form: $f = 0.5(N-1)$. Thus, the score for a redundant group of components is: $S_{max} + 0.5(N-1)$. See Figure 4-2 for an example.

c) **Rules for dependent systems.** When a group of components is linked by an "**and**" gate (indicating dependency), the recommended overall score for that group is the lowest of the component scores, S_{min}. See Figure 4-3 for an example.

d) **Other methods.** If justified by additional analyses, other combination methods may be used in place of those recommended here.

e) **Special Considerations.** System reliability can be affected by circumstances, such as requirements for operator actions (e.g. reset of relays), inaccessibility to components and controls, or general reliability (e.g., a history of maintenance problems with a piece of equipment). These factors may have already been addressed during the system identification described in Chapter 2. They will have an effect on the risk management portion of this assessment, as described in Chapter 5. Any special considerations related to system function should be noted so they can be evaluated and addressed as part of the risk management implementation.

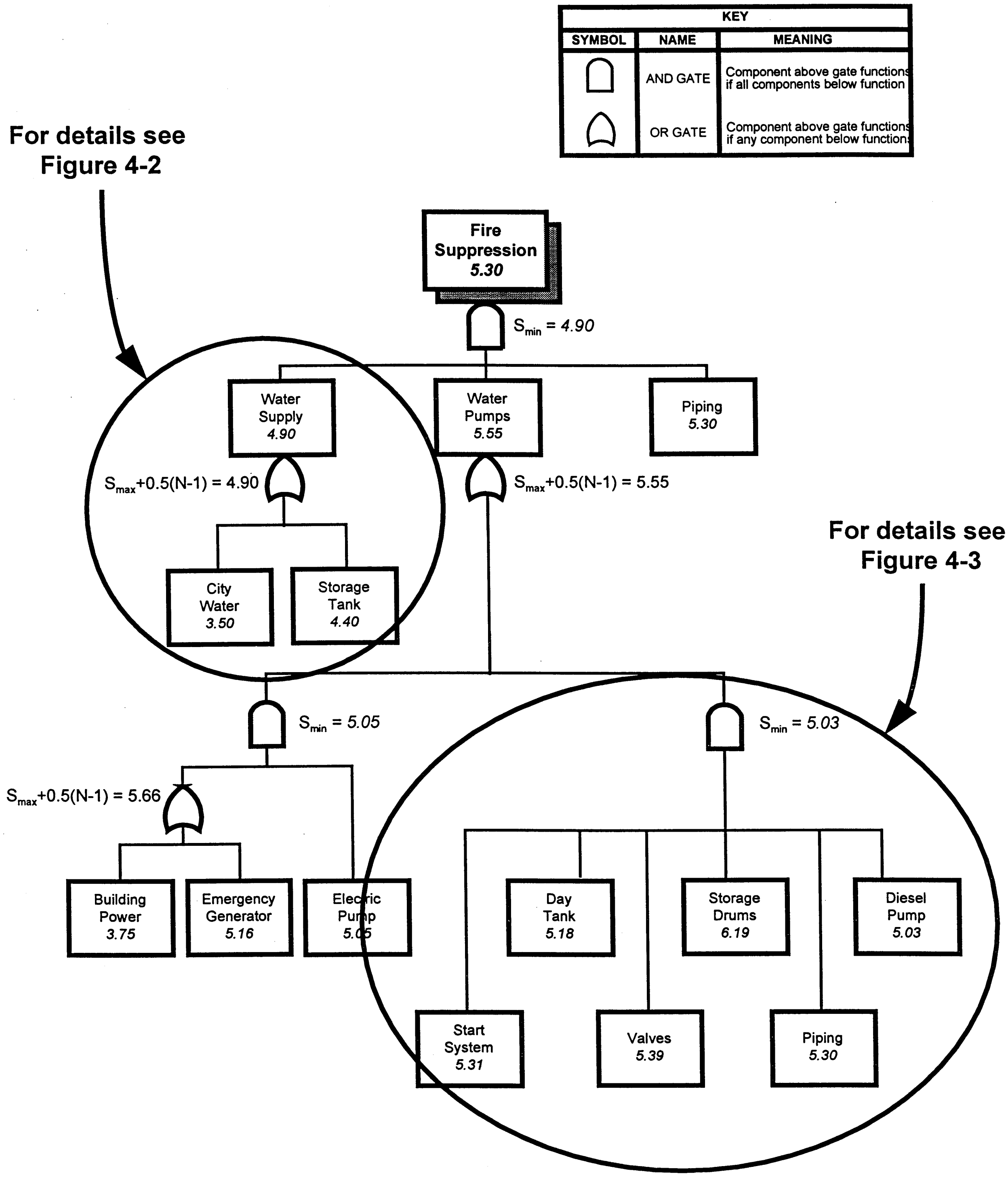
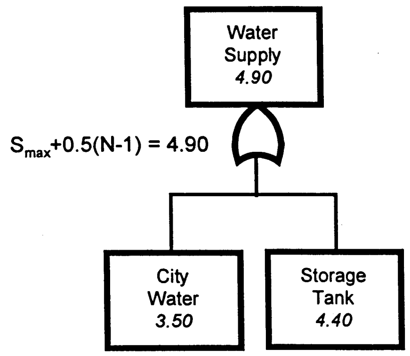
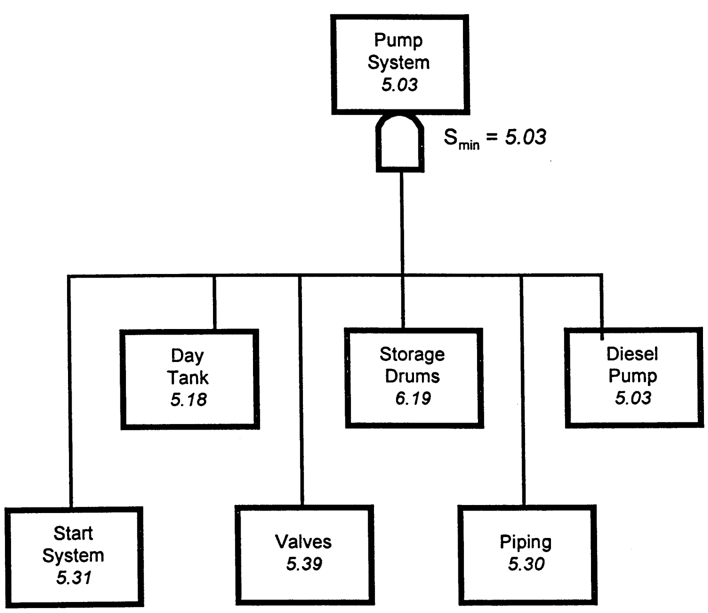


Figure 4-1: Illustration of system scoring
Numbers shown were selected for illustrative purposes only.



The water supply can be provided by either an on-site storage tank or a connection to the municipal water supply. The score for this redundant subsystem is dependent on the number of redundant components (N = 2) and the highest component score (S_{max} = 4.40). The formula to calculate the water supply score is shown above.

Figure 4-2: Sample Redundant System



The pump system will not function unless all its components function. The score for this dependent system is controlled by the lowest component score. In this case the diesel pump (S = 5.03) is the controlling component.

Figure 4-3: Sample Dependant System

CHAPTER 5
RISK MANAGEMENT

5.1 INTRODUCTION

Previous chapters of this recommended practice have provided methods for identifying critical systems and components and performing component and systems evaluations. This chapter discusses the use of the results of all of these evaluations to achieve the overall goal of this recommended practice, to increase the reliability of critical systems to an acceptable level.

The results of the screening methodology provide a basis for making risk management decisions. The review of critical electrical and mechanical systems and their components provides the information necessary to create a specific plan for improving a facility's post-earthquake functionality. To accomplish this, the reviewer must do the following:

a) Review the results of the systems evaluation to identify which systems constitute potential weaknesses in overall facility reliability, and which components constitute weaknesses in each system reliability.

b) Review the results of component evaluation to determine causes of low reliability of those components identified in step a.

c) Develop an action plan to mitigate risks to an acceptable level.

5.2 RISK MANAGEMENT CONCEPTS

The basic concepts that are part of the screening methodology and how they relate to risk management are discussed in this section. Section 5.2.a describes the screening process and how its results can be used. Section 5.2.b discusses what constitutes a critical component from a reliability standpoint. Section 5.2.c describes how the acceptance criteria determined for a facility affects how the results of the methodology are used. Section 5.2.d describes the mitigation options available.

a) **Screening Assessment.** As discussed in Section 3.2a, and 4.2a, the component and system evaluations described in this recommended practice are part of a screening assessment. It highlights important system components, their interactions, and their impact on system function. It is not the only indicator of where upgrades or repairs should be made, but it provides a consistent method for identifying obvious vulnerabilities and prioritizing risk management implementation, as described in this Chapter.

b) **Scores.** System and component scores are a method of quantifying and comparing system reliability. A higher score indicates a higher reliability. Derivation of the scores is described in Reference 1.8c.

c) **Acceptance Criteria.** Acceptance criteria are established by facility operators and owners, or local governing regulating agencies, as appropriate. Recommended guidelines are presented in Section 5.4. All systems are compared to the acceptance criteria to determine which components and systems should be addressed using one of the mitigation strategies described below.

d) **Mitigation.** Mitigation is not limited to physical repairs to equipment or systems. Mitigation can be achieved through means such as upgrades, analyses and emergency response procedures. All mitigation efforts as defined in this recommended practice are intended to improve overall system reliability. Section 5.5 discusses mitigation strategies.

5.3 RISK MANAGEMENT IMPLEMENTATION

This section describes the process of assessing the results obtained from the screening methodology. Subsequent sections discuss acceptance criteria, mitigation methods and emergency preparedness plans in greater detail. The flow chart in Figure 5-1 visually describes the implementation process. The main elements of the overall implementation process are as follows:

a) **Acceptance Criteria.** A score has been calculated for each critical system identified and reviewed during the screening process. Each system should be ranked using these scores so that the highest risk systems (lowest scores) are assigned as the highest priority. Examples of suggested risk categories to be used for acceptance criteria are presented in Section 5.4 and Table 5-1.

b) **Identify and Review Controlling Components.** For every critical system, the component(s) causing the "low" system score should be identified. These critical components should be reviewed in more detail. The first step is to verify that the basic score and modifiers were correctly applied during the screening process. Ensure that there is no additional information available that could be included to reduce conservatism of the original analysis. An action plan should then be developed to mitigate the vulnerabilities. It is import to address all vulnerabilities that could would cause the system score to not meet the acceptance criteria, not just the "worst case" vulnerability, i.e. the highest assigned PMF, identified during the screening process.

c) **Identify Mitigation Strategies.** As part of an action plan, one or more of the following methods may be used to increase the calculated reliability of critical components. They are discussed in more detail in Section 5.5.

(1) *Perform detailed analyses* - This is used to demonstrate a greater reliability for the component than was previously estimated. It can result from different analysis techniques, or the consideration of additional data made available.

(2) *Upgrade the component* - This can include repairs, replacement or modification of the component.

(3) *Modify the system* - This can be used to bypass the critical component so that it will not adversely affect system function, or to add redundancy to increase reliability of the system.

(4) *Identify other reasonable means or justification.* - This would usually involve an emergency response plan or similar document, and could include procedures for manual intervention to prevent system failure after a seismic event or replacement of damaged equipment with spare parts. These types of justification should be reviewed carefully on a case-by-case basis.

d) **Emergency Preparedness Plan.** After identifying means to achieve desired risk reduction in all critical systems, it is highly recommended that the emergency response plan should be reviewed for each facility. Section 5.6 discusses considerations for this process.

5.4 ACCEPTANCE CRITERIA

The screening process provides results that are useful in ranking systems and components relative to each other. Overall system reliability indicators of critical systems should also be compared to acceptance criteria to determine whether mitigations are necessary. An example acceptance criteria is presented in Table 5-1. The basis for this table is discussed in more detail in Reference 1.8c.

a) It should be noted that these acceptance criteria are to be applied to the systems to address system functionality after an earthquake. They are not intended to provide acceptance criteria for individual components.

b) Scores which are lower than the governing acceptance criteria may be justified, as discussed in Section 5.5d. In those cases, caution should be used to ensure that unsubstantiated assumptions are not made in the justification process.

5.5 MITIGATION

There are many strategies available to reduce the risk present in a component, a system or a facility. This section discusses several methods of mitigating specific items.

For example, using the acceptance criteria and classification of Table 5-1, mitigation would be required for all vulnerabilities that could cause the component to fall into the "high" or "very high" risk categories. There may be multiple vulnerabilities present in a system or in an individual component that would result in such an unacceptable classification. An action plan may involve implementing more than one of the mitigation strategies described below.

a) **Perform Detailed Analyses.** Additional analyses can provide more specific details on whether vulnerabilities can be reduced or eliminated altogether. Examples of detailed analyses include the following:

(1) *Additional Screening Review of Specific Vulnerabilities.* The screening process provides a first look at a piece of equipment or a system. During this process a large number of items are reviewed and some details may not be recorded or may be missed. A reasonable analysis approach should include reassessing the smaller list of important vulnerabilities identified for critical components. This additional review may be performed by engineering personnel.

(2) *Incorporation of Additional Data.* As appropriate, reassess each important vulnerability identified during the screening process, incorporating data not available during the screening process. For example, where equipment anchorage or the attachment of internal components could not be accessed, additional data may be available from drawings or from opening up equipment to inspect anchor bolts, welds, or attachments.

(3) *Anchorage or Load Path Review.* Screening assessments may identify anchorage or the equipment load path as the controlling vulnerability. More detailed analyses may include specific calculations of capacity and comparison to seismic loads. These would generally be performed in conjunction with the governing seismic code, as specified by the regulating agency.

(4) *Systems Interaction Review.* Screening assessments may identify vulnerabilities associated with equipment displacement or impact as the most important. Example calculations to address these issues would be verification of anchorage, or determination of relative displacements and comparison to separations or comparison of resulting stresses to allowable stresses. Codes or

accepted industry standards, as appropriate, should be used to determine whether results are considered acceptable.

(5) *Equipment Specific Concerns.* The screening process may identify concerns for specific components that are related to unique details, configurations, or other concerns that are difficult to address through typical structural calculations. Options for further analysis would include shake table testing or comparison to tests of similar components or a detailed review of the historic performance of the specific equipment type should be performed to demonstrate its acceptability.

b) **Upgrade Components.** Whether demonstrated by detailed analyses or determined to be appropriate based on inspection, some items require repair or replacement to mitigate a vulnerability. The use of one or more of these options should be determined based on the most efficient risk reduction available.

(1) *Repair or Modification.* As appropriate for the component, a vulnerability may be mitigated by repairing or modifying its operation, configuration, construction, or other structural details. Repairs or modifications should not compromise any safety features of the system or component or cause it to operate outside its normally accepted limits.

(2) *Replacement.* As appropriate for the component, a vulnerability may be mitigated by replacement. All replacement items should provide performance equal to or better than the original component and provide an acceptable risk ranking.

c) **Modify System.** Whether demonstrated by detailed analyses or determined to be appropriate based on inspection, some systems may require modification to mitigate a vulnerability. The use of one or more of these options should be determined based on the most efficient risk reduction available.

(1) *Redundancy.* As appropriate for the component, a vulnerability may be mitigated by installing a redundant component or pathway. For maximum benefit the redundancy should be capable of providing the same or better functionality to the system without use of the vulnerable component.

(2) *Bypass.* As appropriate for the component, a vulnerability may be mitigated by bypassing the vulnerable component or pathway using physical or procedural controls. No bypass should compromise any safety features of the system or component or cause it to operate outside its normally accepted limits.

d) **Identify Other Reasonable Means of Justification.** This could involve any of the following:

(1) *Demonstration of adequate emergency plan.* A facility may have an emergency plan that considers earthquake effects and the critical facility functions. It is possible that system failures may be accommodated by other means, such as using other corporate facilities, using spare inventory for a designated time, etc. Section 5.6 discusses several considerations for reviewing these types of plans to ensure appropriate applicability.

(2) *Identification that manual intervention can be utilized.* In some instances, operators will identify that manual intervention is acceptable for specific vulnerabilities, such as reinsertion of circuit boards that may become dismounted. If such an action is used for justification, the appropriateness again should be carefully reviewed. Several items should be verified, such as whether the operator or other qualified personnel are available to perform that function at all times, whether specially trained personnel are required, whether the equipment is easily accessed,

or whether other utilities (e.g. power, water, etc.) are required for the operator to perform the function. This justification should be carefully considered to ensure that any similar concerns are addressed.

(3) *Availability of spare parts or equipment.* A low system score may be justified if the particular components resulting in the low score can be easily repaired within an acceptable time frame and spare parts and equipment are kept in stock. Again, several issues should be carefully reviewed, such as whether the spare parts are readily accessible, whether trained personnel are required and available, whether other services (e.g. power) are required to perform the necessary repair or replacement. This justification should be carefully considered to ensure that any similar concerns are addressed.

5.6 EMERGENCY RESPONSE PLAN

a) **General.** An Emergency Response Plan (ERP) is a set of procedures that provide a method of addressing the most critical functions of emergency response and recovery for a facility. Among other things, an ERP typically contains:

(1) Emergency authorization to activate and conduct operations.

(2) An organized management system for response and recovery operations.

(3) A methodology for gathering and evaluating information on the emergency.

(4) An organized system for providing information and coordinating response to the local community and authorities.

(5) An organized system for the early procurement and allocation of resources.

(6) A methodology for assessing damage and the operation of the facility.

(7) Procedures and policies to address loss of communications.

An ERP does not supersede existing procedures such as those for handling medical emergencies or hazardous materials release. It is meant to supplement those procedures with a cohesive temporary management structure that provides immediate management of response during the period following a major crisis. The plan is activated whenever conditions exist that prevent normal operations from being performed and immediate action is required to save lives, prevent damage to property and restore operations.

b) **Earthquakes.** To address earthquakes properly an ERP, or an assessment supporting an ERP, must consider realistic scenarios that may occur in a moderate or a major event. Examples of earthquake specific concerns are:

(1) Transportation systems (e.g., roadways, railroads, etc.) may be unusable or severely restricted.

(2) Buildings and structures may be damaged.

(3) Multiple systems may be lost during a single event.

(4) Personnel response is unpredictable and may also be hindered by limited access to equipment and controls.

(5) Parts needed for repairs may not be readily available.

(6) Experienced personnel required to perform emergency operations may be unavailable.

(7) Fuel supply runs out

c) **Use of ERP for mitigation.** Part of this recommended practice allows the use of ERP procedures to mitigate certain vulnerabilities. When assessing an ERP for this function, the following should be considered:

(1) Ensure that the plan procedures are appropriate to conditions present following an earthquake as described above.

(2) Ensure that all plausible earthquake scenarios have been considered.

(3) Ensure that procedures are in place for operator action that is necessary to mitigate a seismic vulnerability.

(4) Ensure that personnel training has been considered and implemented for all actions necessary to mitigate a seismic vulnerability.

(5) Ensure that any emergency equipment or necessary controls will be accessible after a seismic event if they are needed to mitigate a seismic vulnerability.

d) **Review of existing ERP.** The flow chart in Figure 5-1 describes the risk management implementation process. The final step in that process is an assessment of the facility ERP. It is recommended that a critical review of the ERP, including considerations specific to earthquake hazards as outlined above, be performed.

Table 5-1: Example Risk Classification and Acceptance Criteria

Risk	Category	Description of Acceptance Criteria
I	Very High	Mitigation via analysis, repair, replacement, or emergency plan procedures to achieve a minimum risk rank of III is recommended within 6 months. Recommended for components and systems with scores below 2.5.
II	High	Mitigation via analysis, repair, replacement,, or emergency plan procedures to achieve a minimum risk rank of III is recommended within 12 months. Recommended for components and systems with scores between 2.5 and 3.5.
III	Moderate	Recommended mitigation includes ensuring that the emergency plan includes procedures for responding to damage to the system or component. Recommended for components and systems with scores between 3.5 and 4.5.
IV	Low	No mitigation recommended. Recommended for components and systems with scores above 4.5.

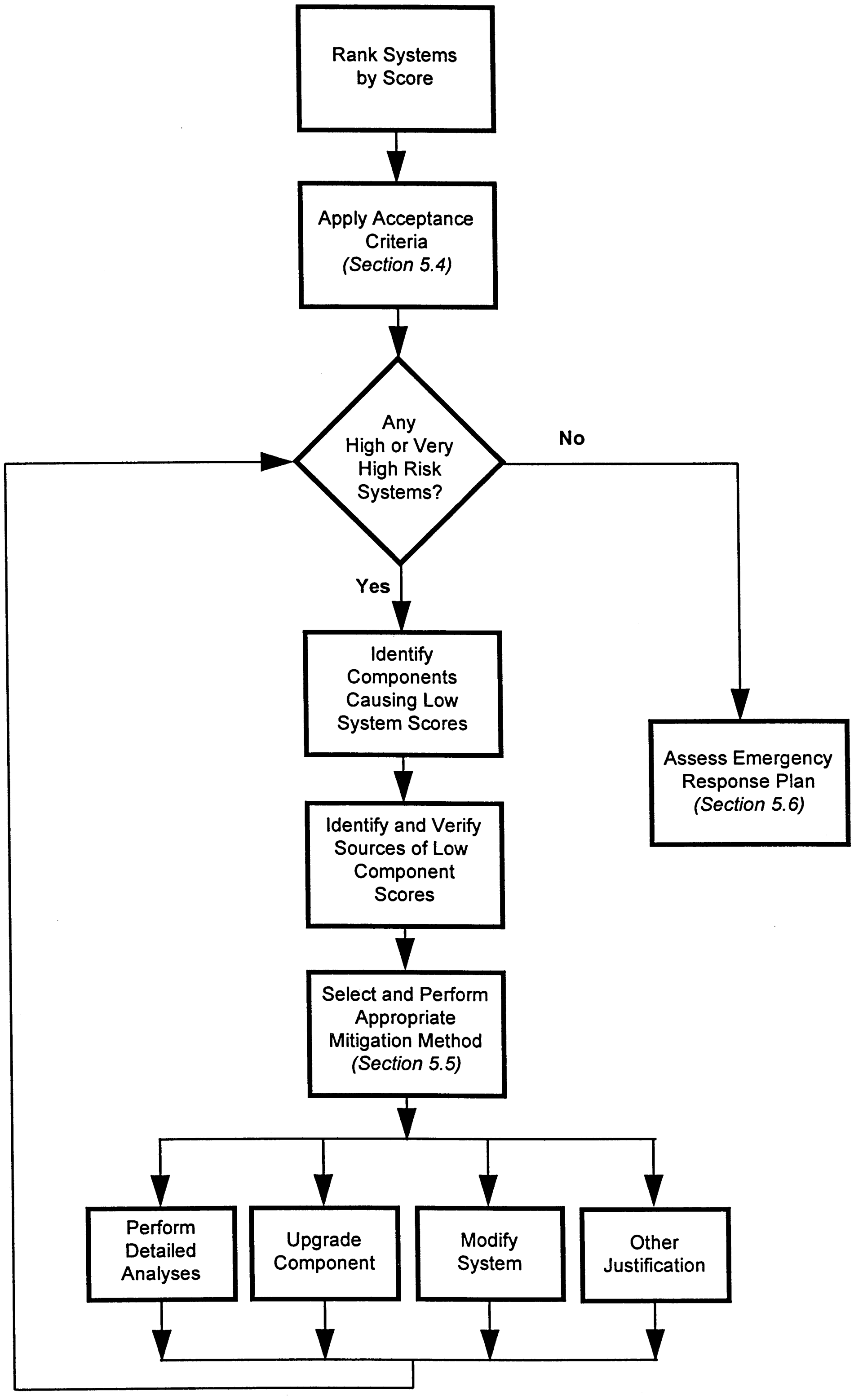


Figure 5-1: Risk Management Implementation

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ISSN 1520-295X